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Comparison of Exclusion Zone Calculations and Vapor Dispersion Modeling Tools

by

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And

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Preface

This Research Project was led by the following individuals:

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References herein to specific commercial products does not necessarily consitute or imply its endorsement, recommendation, or favoring by the Project Team. The views and opinions expressed herein refer to the views and opinions of the Project Team based on the data being evaluated in this Research Project and should not be understood as the views and opinions for all LNG projects. This Research Project is being performed on a generic basis and does not represent an analysis for all types of LNG projects.

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Table of Contents

Section **Page**

ACRONYMS AND TERMS **8**

EXECUTIVE SUMMARY **9**

INTRODUCTION **10**

1 Overview **10**

REGULATORY BACKGROUND **11**

2 Vapor Dispersion Exclusion Zone Requirements **11**

2.1 Federal Code 49 CFR Part 193 History 11

2.2 LNG Vapor Dispersion Exclusion Zone History 11

2.3 Exclusion Zone Definition 12

2.4 Design Spills – Single Accidental Leakage Source History 12

2.5 Modeling Requirement History 13

VAPOR DISPERSION MODELS **15**

3 DEGADIS **15**

3.1 DEGADIS Scenarios 15

3.2 DEGADIS Results Presentation 16

4 Phast **16**

4.1 Phast Scenarios 17

4.2 Phast Results Presentation 17

5 FLACS **17**

5.1 FLACS Scenarios 18

5.2 FLACS Results Presentation 18

VAPOR DISPERSION MODELING SCENARIO DEFINITIONS AND RESULTS PRESENTATION 19

6 Jetting and Flashing 19

7 LNG Conveyance 20

8 LNG Impoundments 21

9 Approach 22

9.1 Task 1: LNG Facility Definition 23

9.2 Task 2: Failure Criteria Definition 23

9.3 Task 3: Design Spill Methodology Comparison 23

9.4 Task 4A: Unmitigated Vapor Dispersion Exclusion Zone Results Comparison 23

9.5 Task 4B: Mitigated Vapor Dispersion Exclusion Zone Results Comparison 24

9.6 Task 4C: Vapor Dispersion Exclusion Zone Graphs 24

9.7 Task 5: Final Report 24

TASK 1: LNG FACILITY DEFINITION 24

10 Bunkering Facility 25

10.1 Basic Process Description 25

10.2 Site Conditions 25

10.3 Design Parameters 25

10.4 Layout Parameters 26

10.5 Plot Plan 28

10.6 3D Geometry 29

11 Export Facility 30

11.1 Basic Process Description 30

11.2 Site Conditions 30

11.3 Design Parameters 30

11.4 Layout Parameters 31

11.5 Plot Plan 33

11.6 3D Geometry 34

12 Fuel Loading Facility 35

12.1 Basic Process Description 35

12.2 Site Conditions 35

12.3 Design Parameters 35

12.4 Layout Parameters 36
12.5 Plot Plan 38
12.6 3D Geometry 38
13 Peakshaver Facility 40
13.1 Basic Process Description 40
13.2 Site Conditions 40
13.3 Design Parameters 40
13.4 Layout Parameters 41
13.5 Plot Plan 43
13.6 3D Geometry 43
TASK 2: FAILURE CRITERIA 45
14 Failure Rate Based Methodology 45
15 Connection Based Methodology 47
TASK 3: DESIGN SPILL METHODOLOGY COMPARISON 48
16 Bunkering Facility 48
16.1 Rundown Line: 48
16.2 Bunkering Line: 48
17 Export Facility 48
17.1 Rundown Line: 48
17.2 Rundown Header: 48
17.3 Marine Loading Line: 49
17.4 Truck Loading Line: 49
18 Fuel Loading Facility 49
18.1 Rundown Line: 49
18.2 Fuel Loading Line: 49
19 Peakshaver Facility 49
19.1 Rundown Line: 49
19.2 Low Pressure Sendout Line to High Pressure Pumps: 50
19.3 High Pressure Sendout Line to Vaporizers: 50
19.4 Truck Loading Line: 50

TASK 4A: UNMITIGATED VAPOR DISPERSION EXCLUSION ZONE RESULTS COMPARISON 50

20 Bunkering Facility Vapor Dispersion Modeling 50

20.1 Jetting and Flashing 50

20.2 LNG Conveyance 63

20.3 LNG Impoundments 75

20.4 Overall Exclusion Zone 87

21 Export Facility Vapor Dispersion Modeling 88

21.1 Jetting and Flashing 88

21.2 LNG Conveyance 115

21.3 LNG Impoundments 138

21.4 Overall Exclusion Zone 149

22 Fuel Loading Facility Vapor Dispersion Modeling 151

22.1 Jetting and Flashing 151

22.2 LNG Conveyance 160

22.3 LNG Impoundments 166

22.4 Overall Exclusion Zone 173

23 Peakshaver Facility Vapor Dispersion Modeling 174

23.1 Jetting and Flashing 174

23.2 LNG Conveyance 188

23.3 LNG Impoundments 199

23.4 Overall Exclusion Zone 206

24 Unmitigated Vapor Dispersion Results Conclusion and Recommendations 209

TASK 4B: MITIGATED VAPOR DISPERSION EXCLUSION ZONE RESULTS COMPARISON 209

25 Mitigation Measures 209

25.1 Vapor Fences 209

25.2 ESD Valves 210

25.3 Emergency Release Systems 212

25.4 Breakaway Couplings 214

26 Mitigated Vapor Dispersion Modeling Assumptions.....217

27 Bunkering Facility Mitigated Vapor Dispersion Modeling 218

27.1 Jetting and Flashing – Emergency Shutdown 218

27.2 Jetting and Flashing – Vapor Fences.....219

28 Export Facility Mitigated Vapor Dispersion Modeling.....222

28.1 Jetting and Flashing – Emergency Shutdown 222

28.2 Jetting and Flashing – Vapor Fences.....223

29 Fuel Loading Facility Mitigated Vapor Dispersion Modeling.....234

29.1 Jetting and Flashing – Emergency Shutdown 234

29.2 Jetting and Flashing – Vapor Fences.....234

30 Peakshaver Facility Mitigated Vapor Dispersion Modeling 239

30.1 Jetting and Flashing – Emergency Shutdown 239

30.2 Jetting and Flashing – Vapor Fences.....239

31 Mitigated Vapor Dispersion Modeling Results Conclusion 248

TASK 4C: VAPOR DISPERSION EXCLUSION ZONE GRAPH..... 248

32 Background 248

33 Vapor Dispersion Exclusion Zone Graph 249

CONCLUSIONS AND RECOMMENDATIONS 251

APPENDIX A – DOT PHMSA FAQ'S (REVISED 12/7/2015) – 2016 REQUIREMENTS 252

APPENDIX B – DOT PHMSA FAQ'S (REVISED 1/10/2017) – 2017 REQUIREMENTS 253

ACRONYMS AND TERMS

Terms	Definition
CFR	Code of Federal Regulations
DEGADIS	Dense Gas Dispersion Model
DOT	Department of Transportation
ESD	Emergency Shutdown
FAQ	Frequently Asked Questions Webpage dated 12/7/2015
FERC	Federal Energy Regulatory Commission
FLACS	Flame Acceleration Simulator model
GRI	Gas Research Institute
LFL	Lower Flammability Limit
LNG	Liquefied natural gas
Marine Transfer Line	An LNG pipeline which transfers LNG from the LNG storage tank to an LNG carrier
NFPA	National Fire Protection Association
Phast	Process hazard analysis software tool
PHMSA	Pipeline and Hazardous Materials Safety Administration
Rundown Header	An LNG pipeline which collects LNG from each individual Rundown Line and transfers it to the LNG storage tanks
Rundown Line	A LNG pipeline originating at the outlet of a liquefaction unit and terminating at the Rundown Header
Project	Research Project
SALS	Single Accidental Leakage Source
Sensitivity Modeling	Modeling to determine how different values of an independent variable change the end result

EXECUTIVE SUMMARY

As part of its ongoing research efforts to address areas for improvement with the requirements for locating liquefied natural gas (LNG) facilities, CH·IV International (CH·IV) was contracted by DOT PHMSA to compare property requirements calculated using approved vapor dispersion modeling tools used to calculate vapor dispersion exclusion zones. The property that operators are required to control is referred to as an exclusion zone.

CH·IV created LNG bunkering, export, fuel loading, and peak shaving plant prototypes based on typical and current facility layouts, design basis, and industry practices. Areas potentially impacted by statistically credible unintended releases of LNG were calculated using guidance adhering to PHMSA's Frequently Asked Questions posted at the inception of the Project. CH·IV modeled the consequences from three release mechanisms: jetting and flashing, conveyance, and impoundment pools.

The resulting areas containing gaseous vapor above prescribed thresholds from jetting and flashing releases were significantly greater than from conveyance or impoundment pool releases.

Overall, the results of the vapor dispersion simulations show that the Phast, FLACS, and DEGADIS models generally provided calculated vapor dispersion distances within a factor of 2 across each model. However, comparison across all models did vary from release to release based on the physical properties, plant geometries, locations, and sizes of each release. The FLACS model was run with and without including facility geometries and the results indicate that the inclusion of geometry has a direct impact on the results. Each model is designed using different methods of calculation and while all models have been validated against LNG experimental results, each model will predict different distances for the same scenario due to each models uniqueness.

All modeling performed for this Project was not site or process specific. Site-specific analysis is required to determine the exclusion zone for a given plant site. In addition, site specific parameters such as temperature, wind speed, humidity, elevation, terrain, overall layout, and process conditions will have a direct impact on vapor dispersion exclusion zones. Therefore, the calculated exclusion zones in this report should not be interpreted as exclusion zones for all facilities.

This Project was initiated in September 2015 and therefore used the DOT PHMSA FAQ requirements at the time (revised 12/7/2015) to calculate vapor dispersion exclusion zones (2016 Requirements). Many of the larger exclusion zones are driven by the 2016 Requirements to determine a single accidental leakage source hole size based on length, which includes large diameter, solid welded piping. Towards the end of this research project and after completion of the GTI Failure Rate Table Research Project, on January 10, 2017, DOT PHMSA updated its FAQ to simplify the process for determining a single accidental leakage source. This January 10, 2017 update no longer requires the use of the failure rate table and provides single accidental leakage source hole sizes based on credible releases informed by the GTI report (2017 Requirements).

Due to the use of the 2016 Requirements as the basis for calculating exclusion zones, many of the simulations had results which extended offsite and required the use of mitigation measures to

reduce the exclusion zones. Mitigation modeling shows that common features included in modern facilities, such as breakaway connections, Emergency Shutdown (ESD) valves, Powered Emergency Release Coupling (PERC) valves, and vapor fences can show a significant decrease in vapor dispersion exclusion zones. The inclusion of ESD valves and shutoff provisions resulted in decreases in vapor dispersion exclusion zones of up to 64% and the inclusion of 20-foot-tall vapor fences resulted in decreases of up to 65%. Although not evaluated, it is expected that taller vapor fences and using vapor fences in combination with ESD shutoff valves would show an even further reduction in vapor dispersion distances. As these results can vary, a site-specific analysis of mitigation features should be performed to determine the effectiveness for each specific project.

A vapor dispersion exclusion zone graph has been created to help developers understand a high level estimate of potential exclusion zones. This graph can help developers to understand during an early phase of development whether a parcel of land will be suitable for the proposed project or if mitigation will be needed to limit vapor dispersion to the property limits. While this graph can be used as a tool during a feasibility stage, a site-specific analysis must be performed for final determination of exclusion zones.

INTRODUCTION

1 OVERVIEW

Federal regulations for liquefied natural gas (LNG) facilities require operators to provide many layers of protection from the risks inherent to facilities that process hydrocarbons. One layer of protection is the control of property that limits the risk to the public from a credible, unintended release of LNG. Operators are required to model the consequences from a credible release from three mechanisms: (1) jetting and flashing, (2) conveyance, and (3) impoundment. The operator uses approved simulation software to predict the potential distance where vapors or radiant heat flux exceed a prescribed threshold. This impacted area is referred to as the exclusion zone.

CH·IV International (CH·IV) executed a project comparing exclusion zones calculated using approved simulation models (Project) for Department of Transportation's Pipeline and Hazardous Materials Safety Administration (DOT PHMSA).

The Project provides a brief history of the different methodologies used to determine a single accidental leakage source (SALS) and a comparison of the design spills for those SALS using the DEGADIS, Phast and FLACS models approved by DOT PHMSA.

Other hazards such as refrigerant dispersion, overpressure, jet fires, and toxics which may be required to be evaluated when performing a hazard analysis but do not constitute an exclusion zone were excluded from this Project.

REGULATORY BACKGROUND

2 VAPOR DISPERSION EXCLUSION ZONE REQUIREMENTS

2.1 Federal Code 49 CFR Part 193 History

The Pipeline Safety Act of 1979 required DOT to implement siting requirements for LNG facilities, as well as standards for the design, construction, testing, operation and maintenance of LNG facilities. Prior to July 1, 1976, no official federal safety standards for LNG facilities existed. Between July 1, 1976, and February 11, 1980, LNG facilities were required to comply with NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (1972 edition) and 49 CFR Part 192.

A report issued on July 31, 1978, by the General Accounting Office titled "Liquefied Energy Gases" highlighted some of the safety concerns in the transportation and storage of LNG. Foremost among those were: (1) protection of persons and property near an LNG facility from thermal radiation caused by ignition of a major spill of LNG, (2) protection of persons and property near an LNG facility from dispersion and delayed ignition of a natural gas cloud arising from a major spill of LNG, and (3) reduction of the potential for a catastrophic spill of LNG. Because of the difference in format and the need for additional regulatory language to facilitate enforcement, a few sections of NFPA 59A were rewritten for their adoption in 49 CFR Part 193.

On February 11, 1980 the current standard, 49 CFR Part 193, was issued as a final rule to address the requirements of the Pipeline Safety Act of 1979.

On March 1, 2000, DOT published another final rule amending the 1980 safety regulations in 49 CFR Part 193 to incorporate NFPA 59A (1996) and again on April 4, 2004, DOT PHMSA published the final rule to amend the safety regulations in 49 CFR Part 193 to incorporate NFPA 59A (2001).

On August 11, 2010, another final rule was issued to incorporate limited areas of NFPA 59A (2006 edition).

2.2 LNG Vapor Dispersion Exclusion Zone History

In 1980, 49 CFR Part 193 required an operator or governmental authority to control the property with an "exclusion zone" to protect the public from the potential adverse effects of thermal radiation and flammable gas dispersion in the event of an LNG release.

Currently, federal code 49 CFR §193.2059, requires that "Each LNG container and LNG transfer system must have a [vapor] dispersion exclusion zone in accordance with sections 2.2.3.3 and 2.2.3.4 of NFPA 59A (incorporated by reference)". Section 2.2.3.4 of NFPA 59A (2001 edition) requires that "provisions shall be made to minimize the possibility of a flammable mixture of vapors from a design spill reaching a property line that can be built upon and that would result in a distinct hazard."

2.3 Exclusion Zone Definition

An "Exclusion Zone" is defined as an area surrounding an LNG facility in which an operator or government agency legally controls all activities in accordance with 49 CFR §193.2057 and 49 CFR §193.2059 for as long as the facility is in operation.

In comments on the Draft Environmental Impact Statement for the Yukon Pacific LNG Project, DOT's Office of Pipeline Safety stated that prohibited activities within an exclusion zone do not include transient travel. Additionally, the Federal Energy Regulatory Commission (FERC) stated recently in the Cameron LNG, LLC BOG Liquefaction Project Environmental Assessment that "in previous informal interpretations of Part 193 requirements, DOT has stated that areas of transient travel through exclusion zones are not prohibited by Part 193" and that highways "would be considered an area of transient travel."

In addition, DOT PHMSA's FAQs[1] state that "As long as the facility is in operation, the operator is responsible for assuring compliance with the limitations on land use within exclusion zones, according to the descriptions in NFPA 59A Sections 2.2.3.2, 2.2.3.3 and 2.2.3.4. For example, an exclusion zone that extends past a property line into a navigable body of water or onto a public road is typically acceptable. This may not hold true if that body of water contains a dock or pier that is not controlled by the operator of the LNG plant or if another entity could erect a building or members of the public could assemble within the exclusion zone. It is possible to assure compliance by legal agreement with a property owner affected by the exclusion zone, such that the land use is restricted for the life of the LNG plant."

2.4 Design Spills – Single Accidental Leakage Source History

Prior to the incorporation of NFPA 59A into 49 CFR Part 193, the design spill in 49 CFR Part 193 assumed the rupture of a single transfer pipe with the greatest overall flow capacity. The National Technology Transfer and Advancement Act of 1995 encouraged federal agencies to use standards developed by private and/or consensus organizations. In accordance with this act, NFPA 59A was adopted into 49 CFR Part 193 which added definition to the requirements for design spills.

For storage tanks, NFPA 59A Table 2.2.3.5 defines design spills for various tank configurations.

- For containers with penetrations below the liquid level without internal shutoff valves, the design spill is a spill through an assumed opening at, and equal in area to, that penetration below the liquid level resulting in the largest flow from any initially full container.
- For containers with penetrations below the liquid level with internal shutoff valves, the design spill is the flow through an assumed opening at and equal in area to, that penetration below the liquid level that could result in the largest flow from an initially full container.

[1] https://www.phmsa.dot.gov/faqs/liquefied-natural-gas, revised 1/10/2017.

- For containers with over the top fill with no penetrations below the liquid level, the spill is the largest flow from any single line that could be pumped into the impounding area with the container withdrawal pumps considered to be delivering the fill rated capacity.

For process areas, NFPA 59A Table 2.2.3.5 defines the spill as the flow from any single accidental leakage source (SALS). Unfortunately, the term SALS is not defined in NFPA 59A. To clarify the selection of design spills, FERC sent a letter to DOT PHMSA on April 19, 2005 requesting clarification on the determination of a SALS. In giving credit to the integrity of all welded transfer piping, FERC staff based the determination on an evaluation of small diameter attachments and any flanges that may be used at valves or equipment. DOT PHMSA confirmed this approach to FERC in a letter returned on May 6, 2005.

While this clarification from FERC and DOT PHMSA provided some guidance, it did not provide full quantitative justification for selecting design spills. As a result, FERC received proposals from applicants using a wide variety of SALS ranging from valve packing leaks to full guillotine ruptures in some applications.

In order to establish a consistent criterion for the selection of SALSs, FERC staff noted that the design spills associated with LNG storage tanks as detailed in NFPA 59A (2001) had an estimated failure once every 20,000 to 30,000 years based on industry publications and therefore used that criteria (3 x 10e-5) to establish the threshold for determining a SALS. As this failure mode was specified in NFPA 59A (2001), FERC staff used the associated failure rate with the failure of a storage tank outlet line to establish a threshold in determining single accidental leakage sources for various spill scenarios. DOT PHMSA has concurred with this approach and has developed an LNG FAQ webpage to provide applicants guidance on determining an appropriate SALS. This approach is discussed further in detail in the Failure Criteria section of this Report.

2.5 Modeling Requirement History

The 1980 issuance of 49 CFR Part 193[2] incorporated the Gaussian Line-Source (GLS) model described in appendix B of a 1974 technical report titled “Evaluation of LNG Vapor Control Methods” which was used to calculate a vapor dispersion exclusion zone. The report also prescribed the conditions that had to be followed in executing that model which included a method for determining the vaporization rate, or source term, to be used as a model input.

In 1997, the Dense Gas Dispersion (DEGADIS) model replaced the GLS model. In addition, DOT PHMSA’s regulations were modified to allow operators to use an equivalent personal computer program to determine a vaporization rate which led to the wide spread use of the SOURCE5 model. In 2000, the vaporization design rate requirements to obtain administrator’s approval were repealed to allow operators more flexibility in computing the formation of the source term.

[2] OPSO 46, February 11, 1980 Final Rule, 45 FR 9184

In March 2000, 49 CFR Part 193 was updated and the Final Rule[3] allowed the use of the FEM3A model as an alternative to DEGADIS. Dispersion distances are calculated in accordance with this model as described in Gas Research Institute (GRI) Report "GRI-96/0396.5 Evaluations of Mitigation Models for Accidental LNG Releases. Volume 5: Using FEM3A for LNG Accident Consequence Analyses".

Until early 2009, the DEGADIS model was the standard used within the LNG industry to calculate vapor dispersion distances to demonstrate that the resulting exclusion zones remain within property controlled by the facility owners or areas controlled by a government entity. However, in an effort to develop LNG dispersion model evaluation tools for the NFPA 59A Committee, the Fire Protection Research Foundation (FPRF) funded research to the United Kingdom Health and Safety Executive's (HSE) Health and Safety Laboratory (HSL) on LNG spill source term modeling and, in March, 2009, its findings were included in a report entitled "LNG Source Term Models for Hazard Analysis: A review of the State-of-the-Art and an Approach to Model Assessment". The report presented a methodology for assessing the suitability of LNG source term models used in determining pool spread and vaporization and concluded that the source term model generally used within the industry to provide input to the DEGADIS dispersion model could result in under-prediction of hazard distances in some cases because it does not accurately represent vapor accumulation within impoundments, vapor flashing and pool spreading.

Subsequently, in July 2010[4,5], DOT PHMSA issued written interpretations acknowledging the FPRF findings that the use of SOURCE5 could lead to non-conservative distances and no longer can be used as an input to DEGADIS. The interpretations also described the requirements that vapor dispersion exclusion zone analysis must include for LNG facilities not yet in existence or under construction to demonstrate compliance with 49 CFR 193. Vapor dispersion analysis should include vapor dispersion from:

- LNG jetting and flashing,
- Conveyance of LNG to impoundments and
- LNG in impoundments.

Although the DEGADIS dispersion model was not a subject of concern for the FPRF, the model is not capable of solving the requirements to analyze the effects of jetting and flashing and the conveyance of LNG spills to impoundments. New models were required to perform this function and therefore, in its written interpretations, DOT PHMSA stated that applicants should provide an interpretation from PHMSA on the suitability of the specific source term model used to satisfy flammable vapor dispersion requirements.

[3] Federal Register Volume 65, No. 41, Docket No. RSPA-97-3002, Amdt. 193-17

[4] July 16, 2010 PHMSA Response Letter to Lisa Tonery, Downeast LNG, Inc.

[5] July 7, 2010 PHMSA Response Letter to John Keppel and Michael Miozza, Weavers Cove Energy, LLC.

On August 30, 2010, DOT PHMSA issued an Advisory Bulletin[6] with guidance on obtaining approval of alternate vapor dispersion models.

VAPOR DISPERSION MODELS

The following sections describe the models approved by DOT PHMSA for vapor dispersion analysis.

3 DEGADIS

The Dense Gas Dispersion Model (DEGADIS) version 2.1 is an integral based model which simulates dispersion at ground level from dense gas clouds released with zero momentum over flat, level terrain. The model was originally developed by the US Coast Guard and the GRI to simulate the dispersion of hazardous liquids or gasses into the atmosphere. DEGADIS is currently incorporated into 49 CFR §193.2059.

The DEGADIS model does not have a built-in source term and requires the model user to define the release source. The DEGADIS model needs a source radius (length) and an evolution rate (mass/time) as an input to the model. Therefore, users must input the source radius and evolution rate along with temperature, wind speed, relative humidity, material properties, and surface roughness factors which the model uses to simulates gas dispersion.

The DEGADIS model is independent of the LNG facility design or terrain.

The FERC with DOT PHMSA as a cooperating agency evaluated DEGADIS against the current Model Evaluation Protocol (MEP)[7] requirements in July 2011[8]. The model is suitable for source terms of regular geometries that may be simplified to a circular area. DEGADIS is suitable for modeling vapor dispersion from LNG pools or impoundments, but not from distributed sources such as trenches or drainage systems. DEGADIS is suitable for wind speeds of 2 m/s, however lower wind speeds may not be handled well by the model. High atmospheric stability (F stability) can be modeled, but may not be handled well by DEGADIS. DEGADIS is limited to unobstructed level terrain. DEGADIS may be able to model jet source terms but only in the vertical orientation – horizontal jets cannot be simulated.

3.1 DEGADIS Scenarios

Consistent with the MEP for DEGADIS, this Project used the DEGADIS model to model dispersion from LNG pool formation in impoundments.

[6] August 31, 2010, PHMSA-2010-0226, ADB-10-07

[7] http://www.nfpa.org/news-and-research/fire-statistics-and-reports/research-reports/hazardous-materials/gases/evaluating-vapor-dispersion-models-for-safety-analysis

[8] Details on the DEGADIS MEP can be found at the following link: https://www.ferc.gov/industries/gas/indus-act/lng/degadis-report.pdf

3.2 DEGADIS Results Presentation

This Project illustrated DEGADIS results without facility geometry on facility plot plans.

DEGADIS results without geometry do not include any of the facility components. As there are no components included, the results are not directionally dependent and therefore are illustrated as a circle depicting the furthest possible vapor dispersion distance in any given direction.

4 PHAST

Phast is an integral based model that simulates various potential hazards from a release of various components. Phast includes the Unified Dispersion Model (UDM) which can model dispersion from no-momentum sources (such as a pool or impoundment) and momentum-based release sources (such as jetting and flashing), which also considers droplet formation and rainout.

The Phast model has a built-in source term and numerous release options. Users can input hole sizes, operating properties, release elevations, and locations along with ambient temperature, wind speed, relative humidity and surface roughness factors which the model uses to simulates gas dispersion.

Similar to DEGADIS, the Phast model is independent of the LNG facility design and requires the user to correctly set up the model to properly simulate gas dispersion scenarios. The UDM combines source term information from vaporizing liquid pools and flashing jets (including droplet formation) to calculate the extent of dispersing vapors. Because the model does not have the capability to incorporate LNG facility design features, such as spill containment systems that control pool size, UDM can over predict the vapor dispersion impacts for scenarios which include rainout.

In accordance with DOT PHMSA written interpretations and final decision, Phast V6.6 and 6.7 are suitable for vapor dispersion from LNG in impoundments, but not from distributed sources such as trenches or drainage systems. The model is implicitly found acceptable for modeling the effects of flashing jets, although it has not been validated by PHMSA for such effects.

The DOT PHMSA Final Decision on the approval of the Phast model can be found in PHMSA Docket No. 2011-0075[9]. The Final Decision stated that the Phast model can be used to model dispersion from circular shaped LNG pools, dispersion from LNG pools with low-aspect ratios (including most impoundments), and dispersion from releases in any direction including releases from flashing, venting, vent stacks, and pressure relief discharge. The Phast model may not be appropriate for dispersion from irregular shaped pools, dispersion from LNG pools with high aspect ratios, or dispersion from multiple coincident releases (including multiple release locations).

[9] https://www.regulations.gov/docket?D=PHMSA-2011-0075

4.1 Phast Scenarios

Consistent with the Final Decision for Phast, this Project used the Phast model to model dispersion from jetting and flashing and dispersion from LNG pool formation in impoundments.

4.2 Phast Results Presentation

This Project illustrated Phast results without facility geometry on facility plot plans.

Phast results without geometry do not include any of the facility components. As there are no components included, the results are directionally dependent and therefore are illustrated as a circle depicting the furthest possible vapor dispersion distance in any given direction.

5 FLACS

FLACS is a computational fluid dynamics (CFD) model that simulates dispersion from a release of various components. FLACS takes into account 3D plant physical geometries, obstacles and terrain.

The FLACS model allows users to input source terms, release elevations and locations along with ambient temperature, wind speed, atmospheric stability, and surface roughness factors, which the model uses to simulate gas dispersion. The model has only basic source term capabilities and allows input from other modeling sources to develop the vapor generation rates used in dispersion modeling.

The FLACS model allows a three-dimensional geometry model of the LNG facility to be built, or imported from the engineering company developing the project. In addition to plant equipment, spill containment systems, structures, and buildings, the FLACS geometry model can include other features such as topography, vegetation, and other obstacles or obstructions.

In accordance with DOT PHMSA written interpretations, FLACS V9.1 Release 2 can model the effects dispersing vapors around obstacles and across complex terrain, including sources that are fixed and those that are distributed, such as vapors from LNG conveyance into impoundments and from impoundments. The model is implicitly found acceptable for modeling the effects of flashing jets, although it has not been validated by PHMSA for such effects, as there is no current validation requirement.

The DOT PHMSA Final Decision on the approval of the FLACS model can be found in PHMSA Docket No. 2011-0101[10]. The FLACS model can be used to model dispersion from circular or irregular shaped LNG pools; dispersion from LNG pools with low and high aspect ratios; dispersion from releases in any direction including releases from flashing, venting, vent stacks and pressure relief discharge; dispersion from multiple coincident releases (including multiple release locations that may influence each other); dispersion over sloped terrain with a 10% or less grade; and dispersion over obstructions (including large

[10] https://www.regulations.gov/docket?D=PHMSA-2011-0101

obstructions that may cause wind-channeling and obstructions that may reduce momentum and subsequent mixing of a high pressure release). In some cases, FLACS may not be appropriate to model dispersion under unstable atmospheric conditions (A, B, C stability), dispersion under low ambient pressure (less than 90kPa) or dispersion over varying or sloped terrain with a 10% or greater grade.

5.1 FLACS Scenarios

Consistent with the Final Rule for FLACS, this Project used the FLACS model to model dispersion from jetting and flashing, dispersion from LNG conveyance through spill containment systems, and dispersion from LNG pool formation in impoundments.

5.2 FLACS Results Presentation

This Project illustrated FLACS results both with and without facility geometry on facility plot plans.

FLACS results with geometry include the 3D model of the facility which includes facility components. As inclusion of the geometry will provide obstructions, these results are directionally dependent and the results are illustrated to include the furthest dispersion distance of the cloud, along with the width and size of the cloud. For all jetting and flashing scenarios and conveyance with geometry, multiple release and wind directions are run with FLACS to illustrate how dispersion in different directions can vary slightly based on the geometry that the release encounters. Therefore, the results for the jetting and flashing scenarios have two FLACS illustrations to depict vapor dispersion releases in different directions with different wind directions (i.e. release directions to the North will include wind directions to the North, Northwest, and Northeast with similar simulations modeled for East, West, and South directions) and the results for the conveyance scenario have one single FLACS illustration which is a compilation of vapor dispersion into the spill containment basin with wind to the North, South, East, and West.

FLACS results without geometry do not include any of the facility components. As there are no components included, the results are not directionally dependent and are therefore illustrated as a circle depicting the furthest possible vapor dispersion distance in any given direction.

As indicated in the differences between the FLACS modeling with and without geometry, the inclusion of geometry and obstacles can show a difference in vapor dispersion distances. Although both release scenarios are performed with the same model using the same atmospheric conditions and release conditions, the presence of obstacles and geometry can change the overall dispersion characteristics. These obstacles can disrupt the momentum of a vapor release and require the dispersing vapor to either warm up and move over the obstacle or disperse around the obstacle impacting the vapor dispersion distances.

VAPOR DISPERSION MODELING SCENARIO DEFINITIONS AND RESULTS PRESENTATION

This section describes the modeling scenarios considered and mechanisms associated with an LNG release from equipment.

6 JETTING AND FLASHING

The Phast and FLACS models have been used in this comparison study to calculate the vapor dispersion exclusion zone distances from a jetting and flashing release. As the FLACS model can include facility geometry, modeling runs were performed with and without inclusion of facility geometry for comparison purposes.

The scenarios modeled assume that there will be a hole size (SALS) established in process piping and LNG will be allowed to disperse from that hole. Based on the physical properties of the release, the entire liquid jet of LNG that is released may flash to vapor which disperses directly to the atmosphere with high momentum. Figure 6-1 depicts this scenario.

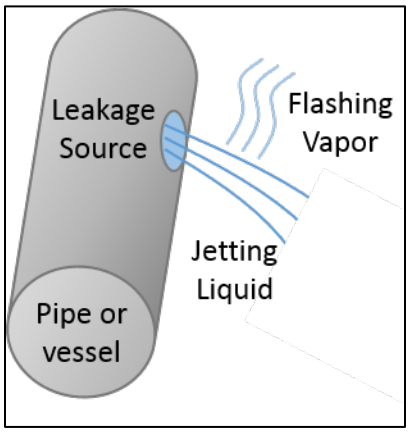

Figure 6-1: Jetting and Flashing Scenario

Depending on operating process conditions, a portion of the release may rain out and form droplets that pool on the ground. The resultant pool will vaporize and disperse directly to the atmosphere as a low momentum release. Figure 6-2 depicts this scenario.

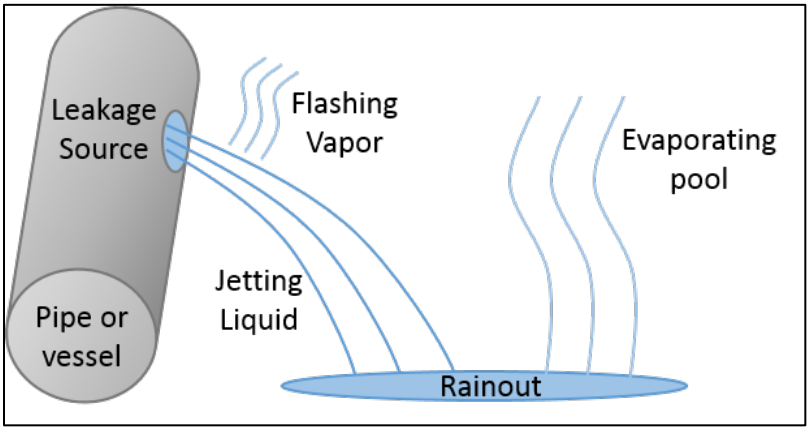

Figure 6-2: Jetting and Flashing with Rainout Scenario

The following legend is used to illustrate the results for all jetting and flashing figures:

Table 6: Jetting and Flashing Figure Legend

Item:	Color:	Notes:
Phast Results	PHAST	Results shown for releases in all directions. Results assume wind direction is in same direction as release direction.
FLACS Results (with facility geometry included)	FLACS	Results shown for releases in specific directions with wind blowing in specific directions.
FLACS Results (without facility geometry included)	FLACS NO GEOMETRY	Results shown for releases in all directions. Results assume wind direction is in same direction as release direction.
Facility Property Line		Illustrates the assumed property line for each generic facility plot plan.

7 LNG CONVEYANCE

The FLACS model was used to determine the vapor dispersion exclusion zones associated with the conveyance of an LNG spill through the spill containment system to the LNG impoundment.

The scenario modeled assumes that LNG liquid spills would be directed into the spill containment system where it would be conveyed to the impoundment. As LNG spills flow through the spill containment system, the LNG warms and vaporizes. The resulting vapor dispersion exclusion zone encompasses the path travelled by the LNG in the spill containment system.

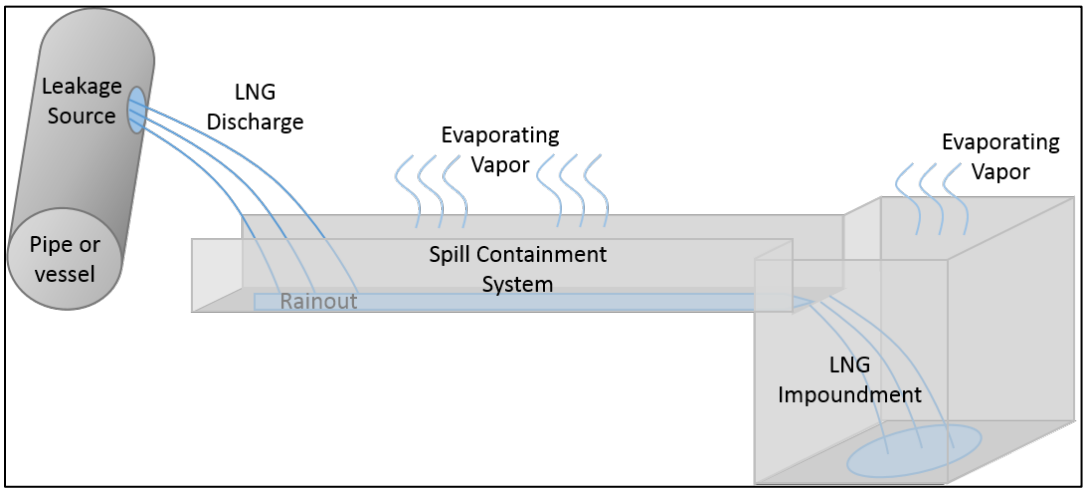

Figure 7: Conveyance Scenario

The following legend will be used for all conveyance figures:

Table 7: Conveyance Figure Legend

Item:	Color:	Notes:
FLACS Results (with facility geometry included)	FLACS	Results shown for releases into the spill containment system towards their impoundment with wind blowing in specific directions.
Facility Property Line		Illustrates the assumed property line for each generic facility plot plan.

8 LNG IMPOUNDMENTS

The DEGADIS, Phast, and FLACS models were used to determine the vapor dispersion exclusion zones associated with LNG spills in the impoundments. These scenarios exclude the spill containment system and model the vapor dispersion that would occur if the entire 10-minute LNG liquid spill collected in the impoundment.

DEGADIS does not have a built-in source term model; therefore, the largest pool vaporization rate for the scenario modeled in Phast is used as the source term for a steady state pool vaporization in DEGADIS. The scenario modeled in DEGADIS assumes the total LNG spill is in the impoundment at time zero and calculates the vapor dispersion over the 10-minute period.

The scenario modeled in Phast assumes that the LNG spills directly into the impoundment at a steady rate, and its vaporization rate is calculated in time steps over the 10-minute spill duration. These pool vaporization rates are then used to model the vapor dispersion. The properties of regular concrete were used for the impoundment modeling.

The scenario modeled in FLACS assumes that the LNG spills directly into the impoundment at a steady rate. Its vaporization rate and associated vapor dispersion distances are

constantly changing variables that are modeled continuously. The properties of regular concrete were used for the impoundment modeling.

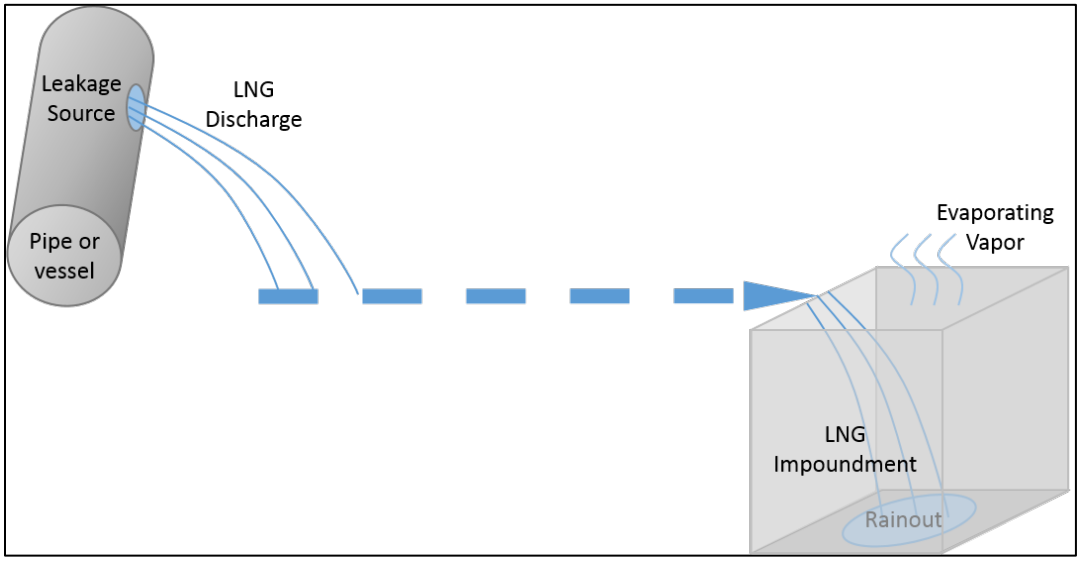

Figure 8: Impoundment Scenario

The following legend will be used for all impoundment figures:

Table 8: Impoundment Figure Legend

Item:	Color:	Notes:
Phast Results	PHAST	Results shown for releases in all directions. Results assume wind direction is in same direction as release direction.
FLACS Results (without facility geometry included)	FLACS NO GEOMETRY	Results shown for releases in all direction. Results assume wind direction is in same direction as release direction.
DEGADIS Results	DEGADIS	Results shown for releases in all directions. Results assume wind direction is in same direction as release direction.
Facility Property Line		Illustrates the assumed property line for each generic facility plot plan.

9 APPROACH

The Project has been broken up into Tasks. The Tasks are defined in a sequential order to follow the path that most developers would use when progressing projects and performing vapor dispersion exclusion zone distances. Each Task forms a prerequisite for subsequent Tasks.

9.1 Task 1: LNG Facility Definition

The Project team identified a generic design basis for the following LNG facility types: import, export, peak-shaving, and mid-scale LNG truck loading. The design basis is broken up into the major areas of an LNG facility (such as marine loading/unloading, tank area, liquefaction area, vaporization area, etc.) and is populated with common design parameters for each area. Research has been performed based on publicly available information on the common parameters for each facility type in order to identify a generic design basis that best represents typical LNG projects.

The design basis includes information necessary to serve as the foundation for vapor dispersion modeling and provide a consistent means for comparing results across different methodologies and modeling tools. The generic design basis captures design elements common to the majority of currently proposed LNG projects.

Separate plot plans have been developed to represent a generic layout of each LNG facility type.

9.2 Task 2: Failure Criteria Definition

The Project team identified the connection-based and failure rate based methodologies used by the 2016 Requirements to determine a SALS and defined a generic Failure Criteria. This serves as the “rules” for calculating a SALS across all facilities.

9.3 Task 3: Design Spill Methodology Comparison

The Project team applied both the Connection-Based Methodology and Failure Rate-Based Methodology to each LNG facility to identify SALSs. This results in a SALSs for each area of the facilities. The SALS is then used as the design spill. The Project includes a comparative discussion on the differences in SALS using two methodologies.

9.4 Task 4A: Unmitigated Vapor Dispersion Exclusion Zone Results Comparison

The Project used the design spills determined in Task 3 to calculate exclusion zones. The DEGADIS, Phast, and FLACS models have been used for this Project.

The DEGADIS and Phast models are integral based models, and the FLACS model is a CFD model requiring the 3D geometry of the facility to be built. The generic plot plans developed in Task 1 based on each generic LNG facility design basis served as the basis for the 3D geometry which was built in FLACS by GexCon to represent the facility.

Vapor dispersion exclusion zones have been calculated for LNG jetting and flashing, conveyance, and impoundment release scenarios. DEGADIS has been used for impoundments, Phast and FLACS have been used for jetting and flashing, and FLACS has been used for conveyance. The modeling results from DEGADIS,

Phast, and FLACS have been plotted on the plot plans to illustrate the modeling differences between the calculated vapor dispersion exclusion zones.

9.5 Task 4B: Mitigated Vapor Dispersion Exclusion Zone Results Comparison

Based on the vapor dispersion modeling results calculated in Task 4A, the Project performed additional modeling to determine the effectiveness of mitigation features and the potential reduction in vapor dispersion distances by using those features.

Common design features to consider for mitigation are vapor fences, emergency shutdown systems, insulated concrete, dry-disconnect couplings, break-away hoses, high expansion foam, pipe-in-pipe systems, hazard detection systems, containment systems and the use of fully-welded piping.

Research has been performed on emergency shutdown systems to determine an appropriate time range for a spill to occur, that spill to be detected, and a process shutdown to complete. This overall duration has been applied to the modeling to reduce the standard 10-minute design spill duration and illustrate the effect of decreasing design spill release durations on exclusion zone distances.

For large spills that result in a vapor cloud crossing a property line, vapor fences have been added to the geometry to illustrate the effective of using vapor fences on exclusion zone distances.

9.6 Task 4C: Vapor Dispersion Exclusion Zone Graphs

Additional modeling has been performed based on generic process conditions to help developers understand if a parcel of land will be suitable for their proposed LNG project. While these diagrams are not meant to be a replacement for a full siting analysis, they can help provide an understanding of what an unmitigated conservative exclusion zone may be early on in a project's development.

9.7 Task 5: Final Report

The Project has created this Final Report (Report) documenting the results from each task and the overall conclusions and recommendations from the research.

TASK 1: LNG FACILITY DEFINITION

Each US LNG Facility is designed, constructed, and operated in accordance with the following codes and standards: NFPA 59A (2001 Edition) and 49 CFR Part 193.

As required by 49 CFR §193.2059, vapor dispersion exclusion zones are limited to only LNG releases, which are assumed to be 100% methane. In accordance with recommendations made by DOT PHMSA in its Final Decisions regarding the use of the FLACS and PHAST dispersion models (dated October 7, 2011) and §193.2059(b)(1), dispersion distances will be measured to the ½ lower flammability limit (LFL). Because the scope of this Project is to evaluate LNG vapor dispersion exclusion zones, other project specific hazards such as refrigerant dispersion and overpressures are not considered.

10 BUNKERING FACILITY

10.1 Basic Process Description

The Facility receives feed gas by a pipeline at a pressure sufficient for pretreatment and liquefaction. The pretreatment system removes carbon dioxide, water and sulfur compounds to meet liquefaction feed gas specifications. Pretreated natural gas is liquefied and transferred to the LNG storage tanks. The LNG is then stored in full containment LNG storage tanks. LNG from the LNG storage tanks is transferred via the bunkering line to fuel marine vessels.

10.2 Site Conditions

Average atmospheric conditions at the site are assumed to be 70°F, 50% relative humidity and wind speed of 2 m/s.

The topography of the site is assumed to be represented with a surface roughness factor of 0.03m as it is assumed that the bunkering facility is located in an existing industrial area and is located adjacent to a narrow ship channel and not adjacent to open water.

In addition to the above values, additional sensitivity modeling using a wind speed of 1 m/s and a surface roughness factor of 0.01m is performed.

10.3 Design Parameters

The following design parameters are used for the Facility:

Table 10.3: Design Parameters

Parameter:	**Value:**
Liquefaction Unit Capacity	8 MMSCFD (~100,000 gpd)
Liquefaction Units	1
Total Liquefaction Capacity	8 MMSCFD (~100,000 gpd)
Liquefaction Rundown Line	2 inch Diameter, Length > 250 feet
Connection Diameter	1 inch Diameter
Liquefaction Rundown Line Conditions	-260°F, 50 psi
LNG Storage Tank Capacity	1,000,000 gallons (3,785 m^3)
LNG Storage Tank Quantity	1

Parameter:	Value:
Bunkering Loading Rate	1,320 gpm supplied by 2 pumps with installed spares. Assumed runout rate of 20%.
Bunkering Line	6 inch Diameter, Length > 490 feet
Connection Diameters	4, 3, 2, and 1 inch Diameter
Bunkering Line Conditions	-260°F, 40 psi
Bunkering Berths	1

10.4 Layout Parameters

The following design parameters will be used for the layout of the Facility:

Table 4: Layout Design Parameters

Parameter:	Value:
Total Site Acreage	34 Acres (1,045 feet x 1,420 feet)
LNG Tank Diameter	70 feet
LNG Inner Tank Height	40 feet
10,000 Btu/ft^2-hr Exclusion Zone for Tank	175 feet
1,600 Btu/ft^2-hr Exclusion Zone for Tank	325 feet
Liquefaction Unit Dimensions	360 feet long by 180 feet wide
Spill Containment	4 feet wide by 4 feet deep trench under all process piping which conveys all spills to the local Impoundment
Impoundment 1 Dimensions	5 feet long by 5 feet wide by 4 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment	25 feet
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment	50 feet

Parameter:	**Value:**
Impoundment Dimensions	35 feet long by 35 feet wide by 2 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment	150 feet
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment	225 feet
Liquefaction Unit and Security Fence Separation	50 feet per NFPA 59A (2001) Section 2.2.6.1

10.5 Plot Plan

The following figure illustrates the generic plot plan developed for the Facility:

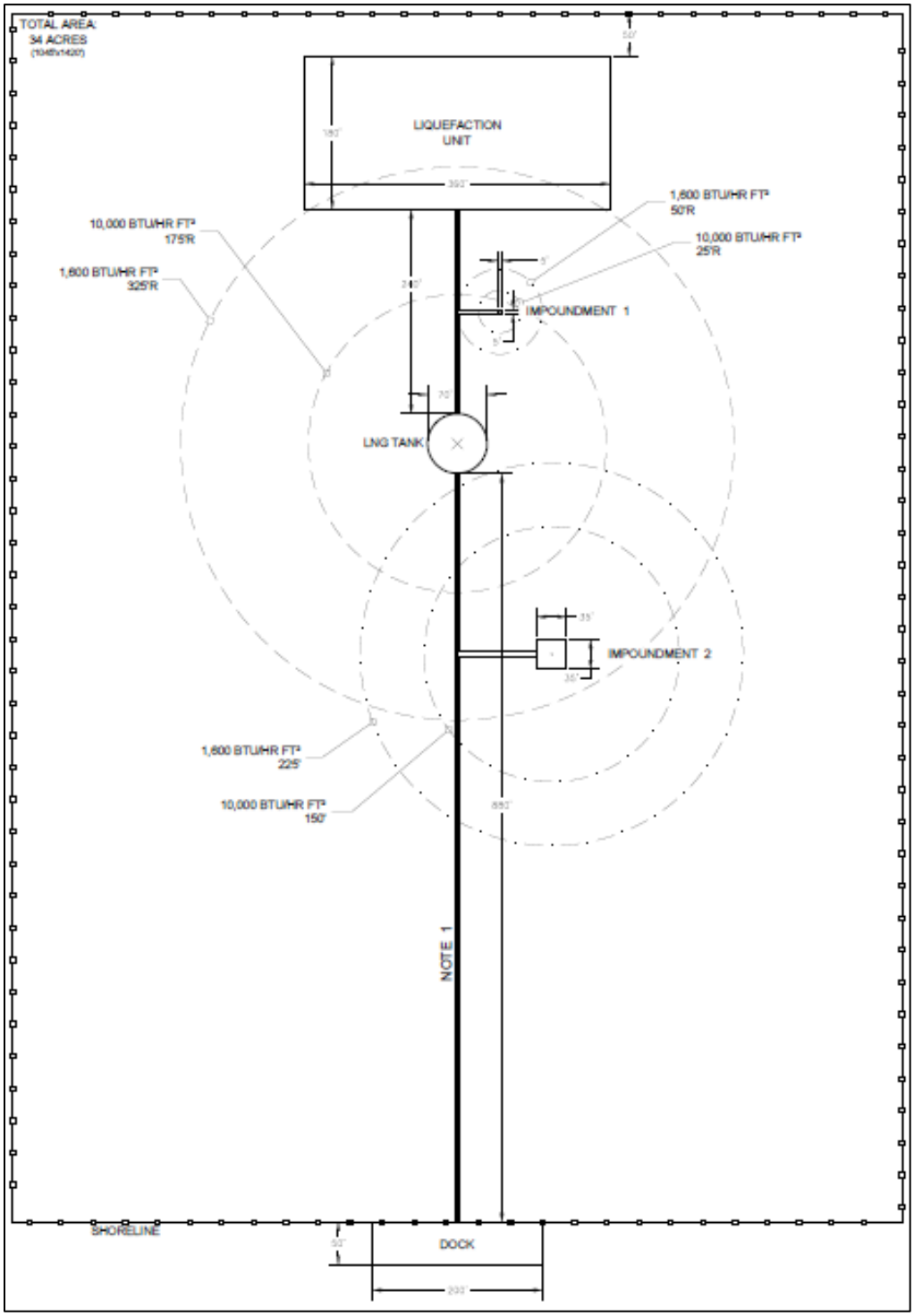

Figure 10.5: Bunkering Facility Plot Plan

10.6 3D Geometry

A three-dimensional model of the LNG bunkering facility was built in FLACS for use in the vapor dispersion modeling. In order to provide realistic results for the generic facility layout selected for the study, the FLACS geometry incorporated several detailed equipment models, such as: a small-scale liquefaction unit, a field-erected LNG storage tank, and a marine loading berth. The geometry was then completed by adding piping on sleepers and a liquid collection and conveyance system, custom built to match the proposed plant layout.

Figure 10.6: Bunkering Facility Plot Plan

11 EXPORT FACILITY

11.1 Basic Process Description

The Facility receives feed gas by a pipeline at a pressure sufficient for pretreatment and liquefaction. The pretreatment system removes carbon dioxide, water and sulfur compounds to meet liquefaction feed gas specifications. Pretreated natural gas is liquefied and transferred to the LNG storage tanks. The LNG is stored in full containment LNG storage tanks. LNG from the LNG storage tanks is pumped to the marine loading facility and loaded onto an LNG carrier. LNG from the LNG storage tanks can also be pumped to a truck loading system.

11.2 Site Conditions

Average atmospheric conditions at the site are assumed to be 70°F, 50% relative humidity and wind speed of 2 m/s.

The topography of the site is assumed represented with a surface roughness factor of 0.03m.

In addition to the above values, additional sensitivity modeling using a wind speed of 1 m/s and a surface roughness factor of 0.01m is performed.

11.3 Design Parameters

The following design parameters will be used for the Facility:

Table 11.3: Design Parameters

Parameter:	**Value:**
Liquefaction Unit Capacity	5 MTPA
Liquefaction Units	3
Total Liquefaction Capacity	15 MTPA
Liquefaction Rundown Lines	Three 16 inch Diameter (one line per train), Length > 490 feet
Liquefaction Rundown Header	28 inch Diameter, Length > 980 feet
Connection Diameters	4, 3, 2, and 1 inch Diameter
Liquefaction Rundown Header Conditions	-260°F, 50 psi
LNG Storage Tank Capacity	160,000 m^3 (42.3 million gallons)

LNG Storage Tank Quantity	3
Marine Loading Rate	12,000 m^3/hr (~52,834 gpm) supplied by 4 in-tank pumps with installed spares in each tank. Assumed runout rate of 20%.
Marine Loading Line	36 inch Diameter, Length > 980 feet
Connection Diameters	4, 3, 2, and 1 inch Diameter
Marine Loading Line Conditions	-260°F, 100 psi measured at tank discharge and 40 psi measured at loading arm.
Marine Loading Berths	1
Truck Loading Bays	2
Truck Loading Rate	300 gpm
Truck Loading Line	4 inch Diameter, Length > 490 feet
Truck Loading Conditions	-260°F, 40 psi
Connection Diameters	3, 2, and 1 inch Diameter

11.4 Layout Parameters

The following design parameters will be used for the layout of the Facility:

Table 11.4: Layout Design Parameters

Parameter:	**Value:**
Total Site Acreage	121 Acres (2,150 feet x 2,447 feet)
LNG Tank Diameter	270 feet
LNG Inner Tank Height	140 feet
10,000 Btu/ft^2-hr Exclusion Zone for Tank	450 feet
1,600 Btu/ft^2-hr Exclusion Zone for Tank	1,000 feet
Liquefaction Unit Dimensions	660 feet long by 480 feet wide

Parameter:	**Value:**
Truck Loading Area Dimensions	100 feet long by 80 feet wide
Spill Containment	4 feet wide by 4 feet deep trench under all process piping which conveys all spills to the local Impoundment
Impoundment 1 Dimensions	28 feet long by 28 feet wide by 29 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment 1	125 feet
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment 1	175 feet
Impoundment 2 Dimensions	60 feet long by 60 feet wide by 20 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment 2	225 feet
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment 2	325 feet
Liquefaction Unit and Security Fence Separation	50 feet per NFPA 59A (2001) Section 2.2.6.1

11.5 Plot Plan

The following figure illustrates the generic plot plan developed for the Facility:

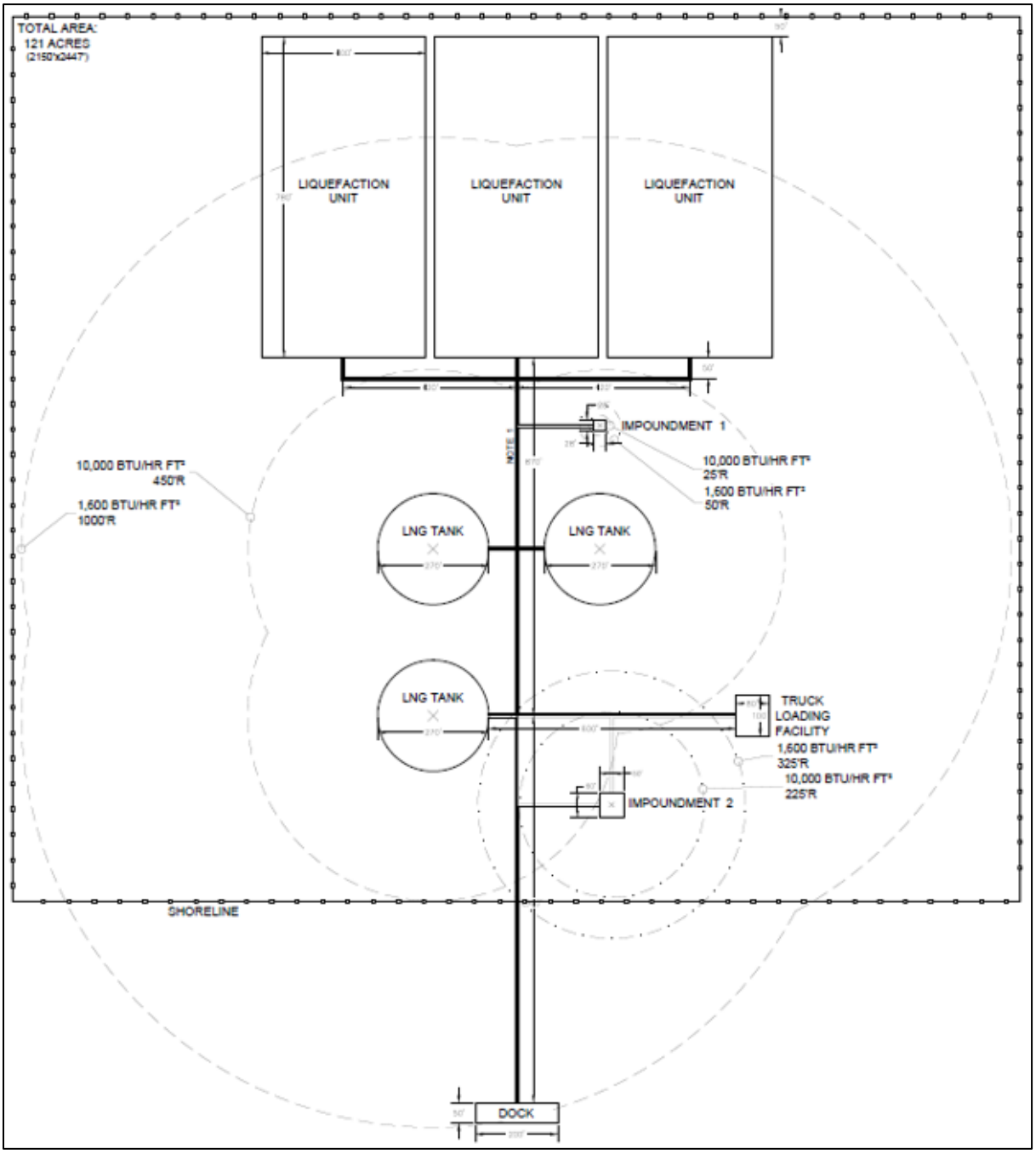

Figure 11.5: Export Facility Plot Plan

11.6 3D Geometry

A three-dimensional model of the LNG export facility was built in FLACS for use in the vapor dispersion modeling. In order to provide realistic results for the generic facility layout selected for the study, the FLACS geometry incorporated several detailed equipment models, such as: three liquefaction trains based on a popular mixed refrigerant process, three field-erect LNG storage tanks, a truck loading facility and a marine loading berth. The geometry was then completed by adding piping (in a piperack or on sleepers) and a liquid collection and conveyance system, custom built to match the proposed plant layout.

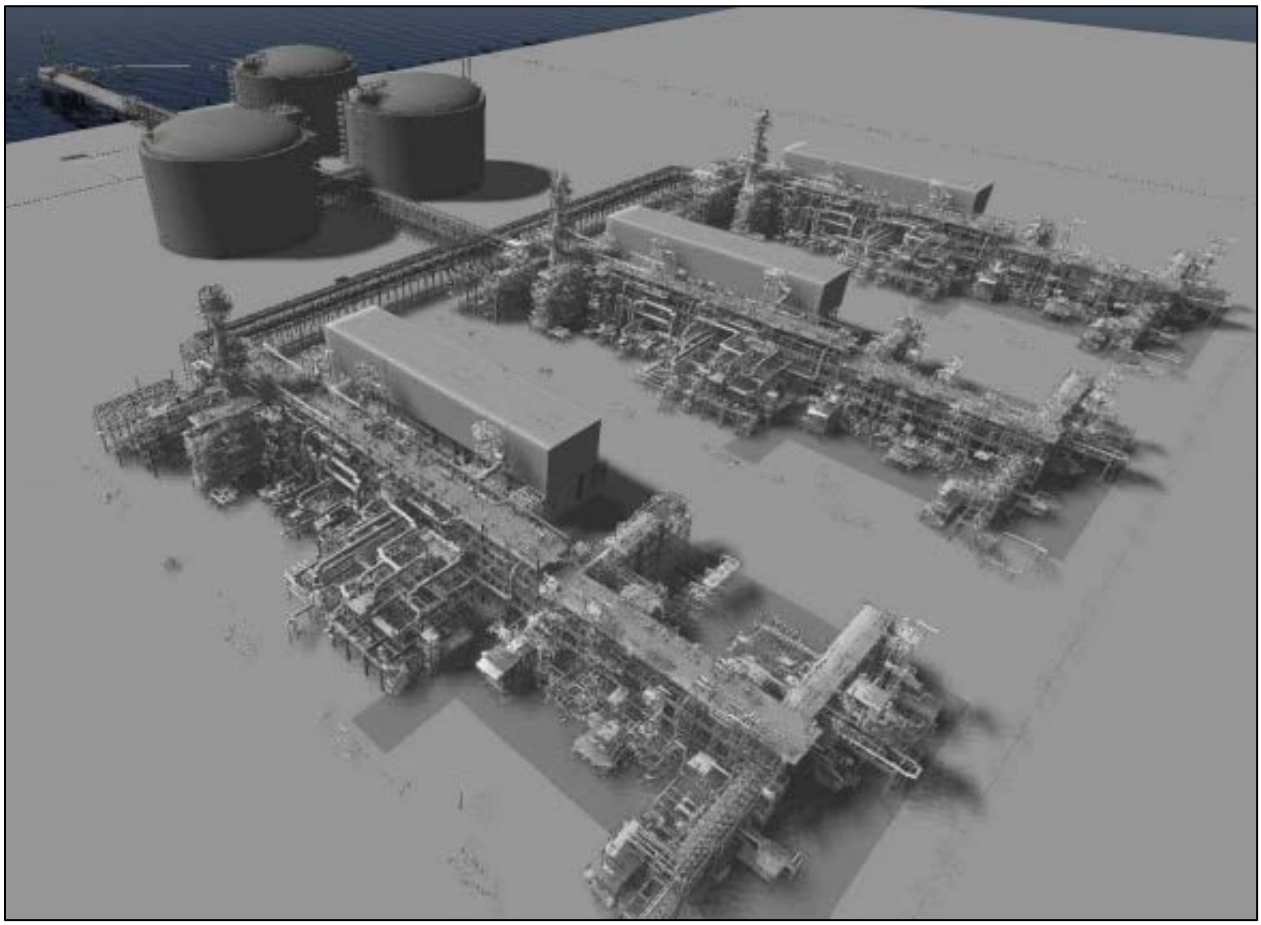

Figure 11.6: Export Facility Plot Plan

12 FUEL LOADING FACILITY

12.1 Basic Process Description

The Facility receives feed gas by a pipeline at a pressure sufficient for pretreatment and liquefaction. The pretreatment system removes carbon dioxide, water and sulfur compounds to meet liquefaction feed gas specifications. Pretreated natural gas is liquefied and transferred to the LNG storage tanks. The LNG is stored in a full containment LNG storage tank. LNG from the LNG storage tank is transferred via the loading line to fuel for end users (railroad tender cars, construction vehicles etc.).

12.2 Site Conditions

Average atmospheric conditions at the site are assumed to be 70°F, 50% relative humidity and wind speed of 2 m/s.

The topography of the site is assumed to be represented with a ground roughness factor of 0.03m.

12.3 Design Parameters

The following design parameters will be used for the Facility:

Table 12.3: Design Parameters

Parameter:	**Value:**
Liquefaction Unit Capacity	8 MMSCFD (~100,000 gpd)
Liquefaction Units	1
Total Liquefaction Capacity	8 MMSCFD (~100,000 gpd)
Liquefaction Rundown Line	2 inch Diameter, Length > 250 feet
Connection Diameters	1 inch Diameter
Liquefaction Rundown Line Conditions	-260°F, 50 psi
LNG Storage Tank Capacity	1,000,000 gallons (3,785 m^3)
LNG Storage Tank Quantity	1
Fuel Loading Rate	300 gpm supplied by 1 pump with installed spare. Assumed runout rate of 20%.

Parameter:	Value:
Fuel Loading Line	4 inch Diameter, Length > 200 feet (spacing estimated based on other projects)
Connection Diameters	3, 2, and 1 inch Diameter
Fuel Loading Line Conditions	-260°F, 40 psi
Fueling Bays	2

12.4 Layout Parameters

The following design parameters will be used for the layout of the Facility:

Table 12.4: Layout Design Parameters

Parameter:	Value:
Total Site Acreage	25 Acres (1,045 feet x 1,045 feet)
LNG Tank Diameter	70 feet
LNG Inner Tank Height	40 feet
10,000 Btu/ft^2-hr Exclusion Zone for Tank	175 feet
1,600 Btu/ft^2-hr Exclusion Zone for Tank	325 feet
Liquefaction Unit Dimensions	360 feet long by 180 feet wide
Fuel Loading Area Dimensions	100 feet long by 80 feet wide
Spill Containment	4 feet wide by 4 feet deep trench under all process piping which conveys all spills to the local Impoundment
Impoundment 1 Dimensions	5 feet long by 5 feet wide by 4 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment 1	25 feet
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment 1	50 feet

Parameter:	**Value:**
Impoundment 2 Dimensions	12 feet long by 12 feet wide by 10 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment 2	75 feet
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment 2	100 feet
Liquefaction Unit and Security Fence Separation	50 feet per NFPA 59A (2001) Section 2.2.6.1

12.5 Plot Plan

The following figure illustrates the generic plot plan developed for the Facility:

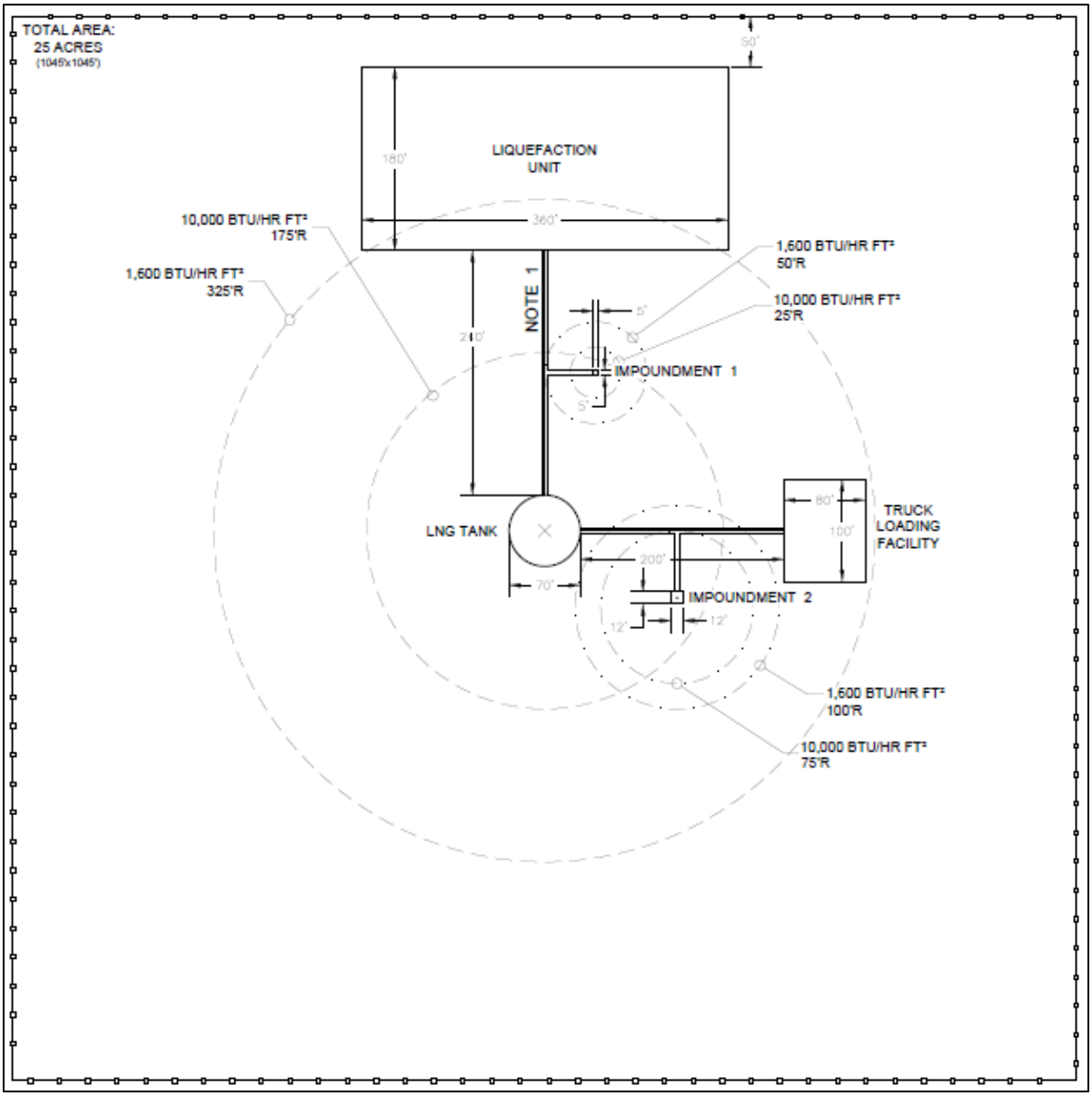

Figure 12.5: Fuel Loading Facility Plot Plan

12.6 3D Geometry

A three-dimensional model of the LNG fuel loading facility was built in FLACS for use in the vapor dispersion modeling. In order to provide realistic results for the generic facility layout selected for the study, the FLACS geometry incorporated several detailed equipment models, such as: a small-scale nitrogen expander liquefaction unit, a field-erect LNG storage tank, and a truck loading facility. The

geometry was then completed by adding piping on sleepers and a liquid collection and conveyance system, custom built to match the proposed plant layout.

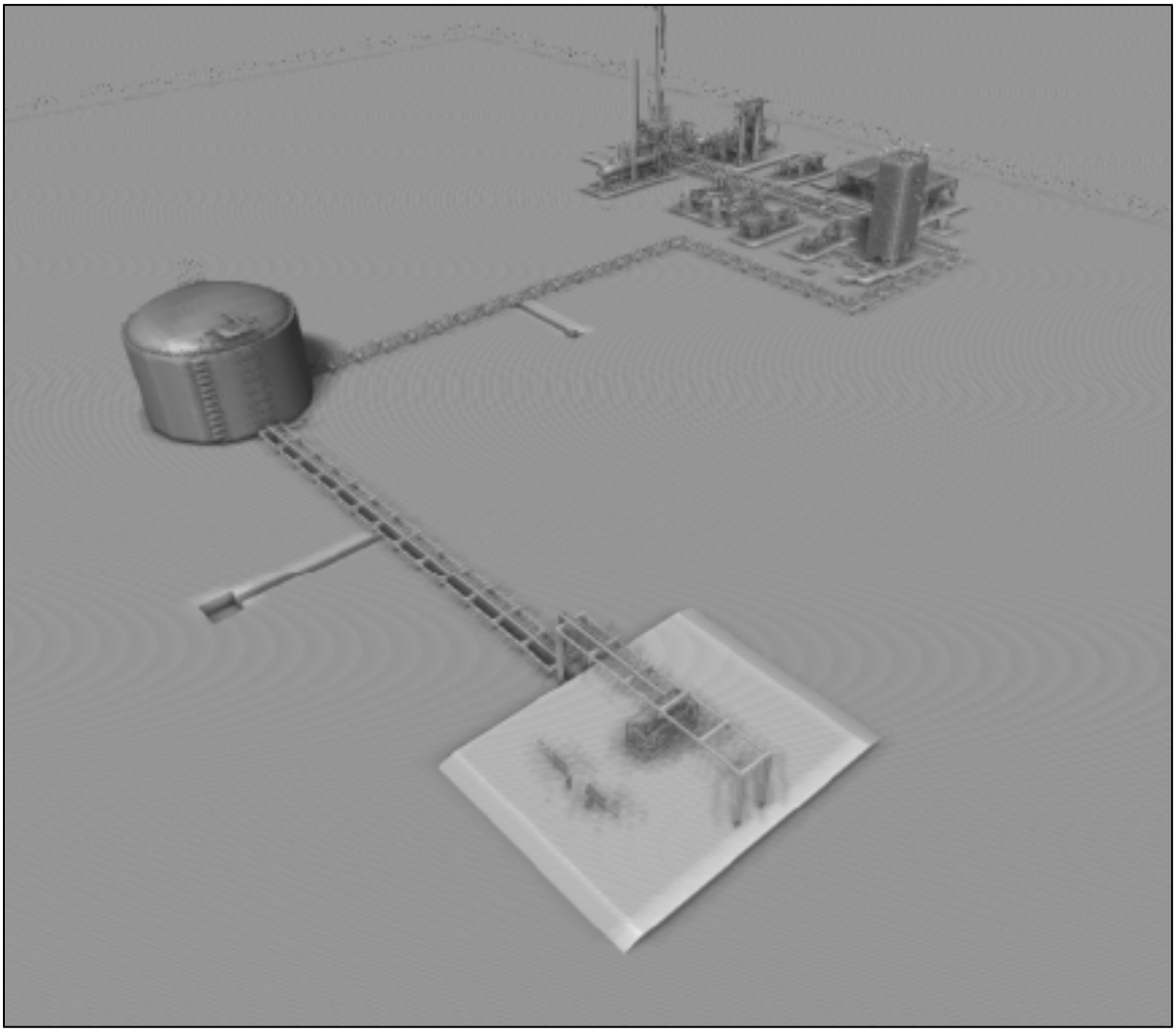

Figure 12.6: Fuel Loading Facility Plot Plan

13 PEAKSHAVER FACILITY

13.1 Basic Process Description

The Facility is supplied feed gas by a pipeline at a pressure sufficient for pretreatment and liquefaction. The pretreatment system removes carbon dioxide, water and sulfur compounds to meet liquefaction feed gas specifications. Pretreated natural gas is liquefied and transferred to the LNG storage tanks. The LNG is stored in a full containment LNG storage tank. LNG from the LNG storage tank is pumped to the high pressure sendout pumps and vaporizers for distribution into a gas pipeline system. LNG from the LNG storage tank can also be pumped to a truck loading system.

13.2 Site Conditions

Average atmospheric conditions at the site are assumed to be 60°F, 50% relative humidity and wind speed of 2 m/s.

The topography of the site is assumed to be represented with a ground roughness factor of 0.03m.

13.3 Design Parameters

The following design parameters will be used for the Facility:

Table 13.3: Design Parameters

Parameter:	**Value:**
Liquefaction Unit Capacity	25 MMSCFD (~311,000 gpd)
Liquefaction Units	1
Total Liquefaction Capacity	25 MMSCFD (~311,000 gpd)
Liquefaction Rundown Line	4 inch Diameter, Length > 490 feet
Connection Diameters	4, 3, 2, and 1 inch Diameter
Liquefaction Rundown Line Conditions	-260°F, 50 psi
LNG Storage Tank Capacity	160,000 m^3 (~42.3 million gallons)
LNG Storage Tank Quantity	1
LNG Storage Tank Sendout	400 MMSCFD (~3,456 gpm) supplied by 4 in-tank pumps. Assumed runout of 20%.

Parameter:	Value:
LP Sendout Line	10 inch diameter, Length >490 feet
Connection Diameters	4, 3, 2, and 1 inch Diameter
LP Sendout Line Conditions	-260°F, 40 psi
HP Sendout Line	10 inch diameter, Length <250 feet (separation distance of ~200 feet based on typical layouts)
Connection Diameters	4, 3, 2, and 1 inch Diameter
HP Sendout Line Conditions	-260°F, 800 psi
Vaporization Unit Capacity	100 MMSCFD
Vaporization Units	4
Total Vaporization Capacity	400 MMSCFD
Truck Loading Bays	2
Truck Loading Rate	300 gpm
Truck Loading Line	4 inch Diameter, Length > 200 feet
Truck Loading Conditions	-260°F, 40 psi
Connection Diameters	4, 3, 2, and 1 inch Diameter

13.4 Layout Parameters

The following design parameters will be used for the layout of the Facility:

Table 13.4: Layout Design Parameters

Parameter:	Value:
Total Site Acreage	95 Acres (2,036 feet x 2,036 feet)
LNG Tank Diameter	270 feet
LNG Inner Tank Height	140 feet
10,000 Btu/ft^2-hr Exclusion Zone for Tank	450 feet

Parameter:	**Value:**
1,600 Btu/ft^2-hr Exclusion Zone for Tank	1,000 feet
Liquefaction Unit Dimensions	360 feet long by 180 feet wide
Vaporization Unit Dimensions	60 feet long by 60 feet wide
Truck Loading Area Dimensions	100 feet long by 80 feet wide
Spill Containment	4 feet wide by 4 feet deep trench under all process piping which conveys all spills to the local Impoundment
Impoundment 1 Dimensions	8 feet long by 8 feet wide by 4 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment	50
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment	75
Impoundment 2 Dimensions	20 feet long by 20 feet wide by 14 feet deep
10,000 Btu/ft^2-hr Exclusion Zone for Impoundment	100 feet
1,600 Btu/ft^2-hr Exclusion Zone for Impoundment	150 feet
Liquefaction Unit and Security Fence Separation	50 feet per NFPA 59A (2001) Section 2.2.6.1

13.5 Plot Plan

The following figure illustrates the generic plot plan developed for the Facility:

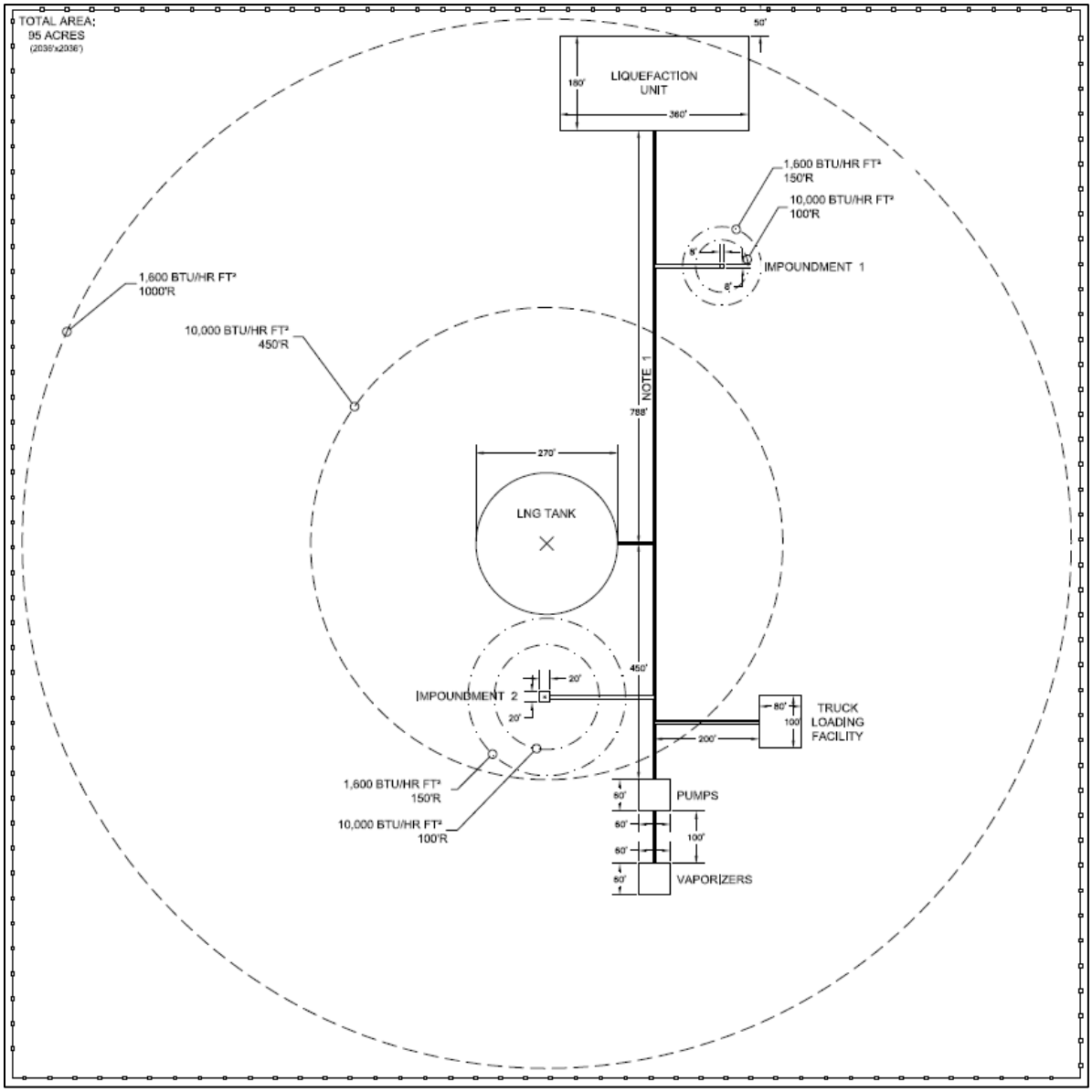

Figure 13.5: Peakshaver Facility Plot Plan

13.6 3D Geometry

A three-dimensional model of the LNG peakshaving facility was built in FLACS for use in the vapor dispersion modeling. In order to provide realistic results for the generic facility layout selected for the study, the FLACS geometry incorporated several detailed equipment models, such as: a small-scale nitrogen expander liquefaction unit, a field-erect LNG storage tank, a truck loading facility, as well as

two LNG pumps and four submerged combustion vaporizers. The geometry was then completed by adding piping on sleepers and a liquid collection and conveyance system, custom built to match the proposed plant layout.

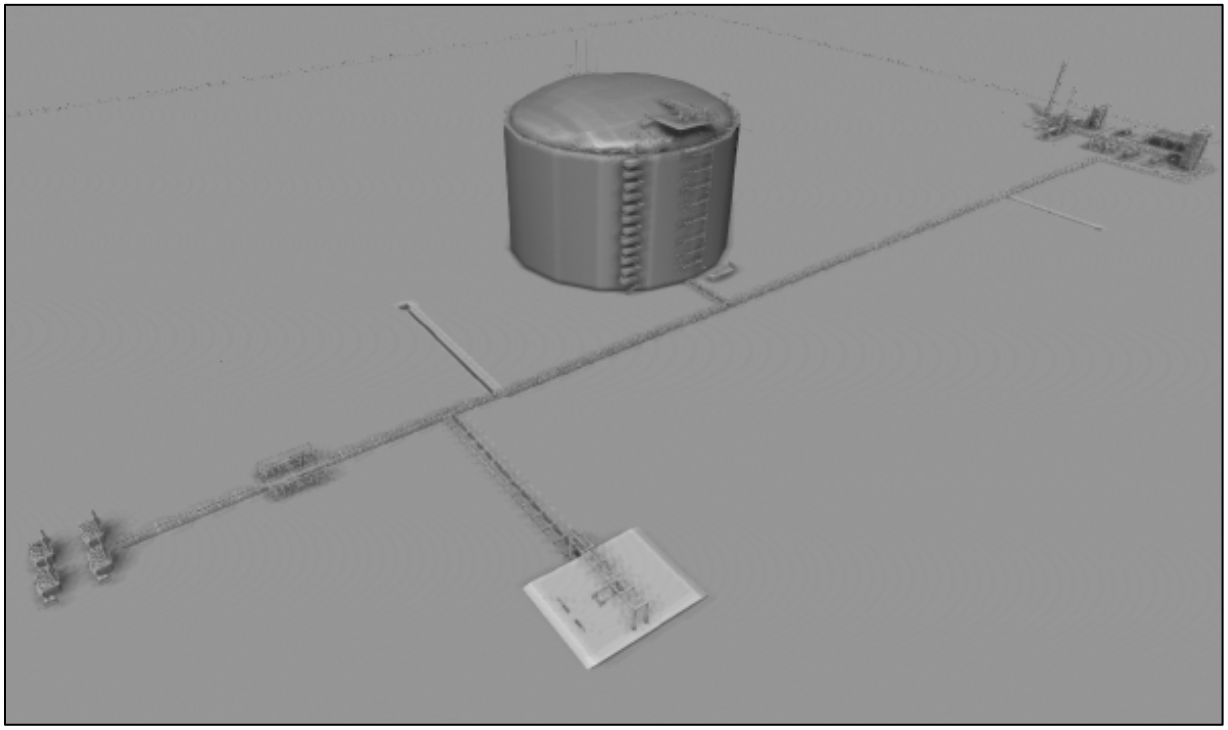

Figure 13.6: Peakshaver Facility Plot Plan

TASK 2: FAILURE CRITERIA

This section will discuss the connection-based and failure rate based methodologies used by the 2016 Requirements to determine a single accidental leakage source and defined a generic Failure Criteria.

14 FAILURE RATE BASED METHODOLOGY

The DOT PHMSA LNG Facility Siting procedure requires preparation of a Piping and Equipment Inventory Database where failure rates and scenarios specified by PHMSA are applied to facility components to determine design spills for each component. The failure rates are maintained on the DOT FAQ webpage. The December 7, 2015 revision of the DOT PHMSA FAQ is used as the basis for this Project and is included in Appendix A of this Report. This procedure expects Front End Engineering Design of the facility to be advanced to the point where detailed Plot Plans, Piperack Section Drawings, Equipment Layouts, Piping and Instrumentation Diagrams, Heat and Material Balances and Process Flow Diagrams are developed.

The following criteria summarize the Failure Rate based methodology used on each facility type:

- A Piping and Equipment Inventory Table of LNG plant components is created.
- For all piping and equipment (including transfer hoses and arms), the failure rate table is applied to determine if the 3 x $10e^{-5}$ per year failure rate criterion is equaled or exceeded.
- For all piping, the failure rate table is applied to a piping segment (i.e., length of pipe), and the hole size is chosen based on equaling or exceeding the 3 x $10e^{-5}$ per year failure rate criterion.
- Regardless of the results obtained by the failure rate table, a minimum 2 inch hole is considered at any location along any piping of 2 inches or larger diameter.
- For all design spill durations, the event is defined in NFPA 59A (2001 Edition) to last "for 10 minutes or a shorter time based on demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction." This Project will assume a 10-minute release duration and will continue vapor dispersion modeling until the 10-minute release reaches its furthest vapor dispersion distance.
- For design spill volumes where pump runout conditions may occur, an increase in 20% over the normal flow rate will be added to account for low pressure runout conditions.
- For any defined maximum hole size based in the failure rate table, a sensitivity analysis will be performed to demonstrate that that the hole size selected produces the greatest vapor dispersion distance when accounting for the mechanisms of jetting, flashing, aerosol formation and rain-out. If a smaller hole size creates a larger vapor dispersion hazard distance, that smaller hole size will be used to define the design spill.
- For each design spill identified, release height and orientation will be selected to define the largest vapor dispersion hazard distance while properly characterizing the

release scenario. For piping segments to which the failure rate table has been applied, the selected hole can occur at any location along the piping segment.

- Process conditions used to determine the design spill will be based on the design basis.

The following Tables illustrate the failure rates used for this Project:

Table 14-1: Failure Rates for Truck and Ship Transfer

Truck Transfer	Failures per year of operation
Rupture of transfer arm	3E-4 per transfer arm
Release from a hole in transfer arm with effective diameter of 10% transfer arm diameter with maximum of 50mm (2-inches)	3E-3 per transfer arm
Rupture of transfer hose	4E-2 per transfer hose
Release from a hole in transfer hose with effective diameter of 10% transfer hose diameter with maximum of 50mm (2-inches)	4E-1 per transfer hose
Ship Transfer	Failures per year of operation
Rupture of transfer arm	2E-5 per transfer arm
Release from a hole in transfer arm with effective diameter of 10% diameter with maximum of 50mm (2-inches)	2E-4per transfer arm

Table 14-2: Failure Rates for Piping

Piping: d < 50mm (2-inch)	Failures per year of operation
Catastrophic rupture	1E-6 per meter of piping
Release from hole with effective diameter of 25mm (1-inch)	5E-6 per meter of piping
Piping: 50mm (2-inch) ≤ d < 149mm (6-inch)	Failures per year of operation
Catastrophic rupture	5E-7 per meter of piping
Release from hole with effective diameter of 25mm (1-inch)	2E-6 per meter of piping
Piping: 150mm (6-inch) ≤d < 299mm (12-inch)	Failures per year of operation
Catastrophic rupture	2E-7 per meter of piping
Release from hole with effective diameter of 1/3 diameter	4E-7 per meter of piping
Release from hole with effective diameter of 25mm (1-inch)	7E-7 per meter of piping
Piping: 300mm (12-inch) ≤d < 499mm (20-inch)	Failures per year of operation
Catastrophic rupture	7E-8 per meter of piping
Release from hole with effective diameter of 1/3 diameter	2E-7 per meter of piping
Release from hole with effective diameter of 10% diameter, up to 50mm (2-inches)	4E-7 per meter of piping
Release from hole with effective diameter of 25mm (1-inch)	5E-7 per meter of piping
Piping: 500mm (20-inch) ≤d < 1000mm (40-inch)	Failures per year of operation
Catastrophic rupture	2E-8 per meter of piping
Release from hole with effective diameter of 1/3 diameter	1E-7 per meter of piping
Release from hole with effective diameter of 10% diameter, up to 50mm (2-inches)	2E-7 per meter of piping
Release from hole with effective diameter of 25mm (1-inch)	4E-7 per meter of piping

15 CONNECTION BASED METHODOLOGY

This methodology requires failures of all connections less than 6 inches in diameter, irrespective of failure rates, piping schedule, orientation, direction or other physical parameters. This methodology is consistent with the FERC letter to DOT PHMSA on April 19, 2005 requesting clarification on the determination of a SALS and the DOT PHMSA response to FERC in a letter returned on May 6, 2005 as further detailed in Section 2.4 of this Report. This methodology expects Front End Engineering Design of the facility to be advanced to the point where Piping and Instrumentation Diagrams, Heat and Material Balances Process Flow Diagrams are developed.

The following criteria summarize the Connection-Based Methodology to be used on each facility type:

- A Piping and Equipment Inventory Table of LNG plant components will be created for each facility type based on each generic design basis.
- For piping connections less than 6 inches in diameter, a full-bore rupture (guillotine failure) is assumed at the point of connection to the equipment item or piping.
- For all design spill durations, the event is defined in NFPA 59A (2001 Edition) to last "for 10 minutes or a shorter time based on demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction." This Project will assume a 10-minute release duration and will continue vapor dispersion modeling until the 10-minute release reaches its furthest vapor dispersion distance.
- For design spill volumes where pump runout conditions may occur, an increase in 20% over the normal flow rate will be added to account for low pressure runout conditions.
- The release location is identified at the specific point of connection in the LNG plant.
- Process conditions used to determine the design spill will be based on the design basis.

TASK 3: DESIGN SPILL METHODOLOGY COMPARISON

The Failure Criteria defined in Task 2 was applied to the facility Design Basis and generic Plot Plans defined in Task 1 to calculate the SALS and their corresponding design spills. The following sections describe and compare the SALS calculated by each methodology which are used as design spills:

16 BUNKERING FACILITY

16.1 Rundown Line:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 2 inch hole, whereas the Connection Methodology predicts up to a 1 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

16.2 Bunkering Line:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 6 inch hole, whereas the Connection Methodology predicts up to a 4 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

17 EXPORT FACILITY

17.1 Rundown Line:

The Failure Rate Methodology predicts up to a 1/3 diameter failure resulting in a 5.3 inch hole, whereas the Connection Methodology predicts up to a 4 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

17.2 Rundown Header:

The Failure Rate Methodology predicts up to a 1/3 diameter failure resulting in a 9.3 inch hole, whereas the Connection Methodology predicts up to a 4 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

17.3 Marine Loading Line:

The Failure Rate Methodology predicts up to a 1/3 diameter failure resulting in a 12 inch hole, whereas the Connection Methodology predicts up to a 4 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

17.4 Truck Loading Line:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 4 inch hole, whereas the Connection Methodology predicts up to a 3 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

18 FUEL LOADING FACILITY

18.1 Rundown Line:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 2 inch hole whereas the Connection Methodology predicts up to a 1 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

18.2 Fuel Loading Line:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 4 inch hole, whereas the Connection Methodology predicts up to a 3 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

19 PEAKSHAVER FACILITY

19.1 Rundown Line:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 4 inch hole, whereas the Connection Methodology predicts up to a 3 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

19.2 Low Pressure Sendout Line to High Pressure Pumps:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 10 inch hole, whereas the Connection Methodology predicts up to a 4 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

19.3 High Pressure Sendout Line to Vaporizers:

The Failure Rate Methodology predicts up to a 1/3 diameter failure resulting in a 3.3 inch hole, whereas the Connection Methodology predicts up to a 4 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

19.4 Truck Loading Line:

The Failure Rate Methodology predicts up to a full guillotine failure resulting in a 4 inch hole, whereas the Connection Methodology predicts up to a 3 inch hole.

The Failure Rate Methodology requires a hole to be located anywhere along the length of that line whereas the Connection Methodology requires a hole to be located at the point of connection.

TASK 4A: UNMITIGATED VAPOR DISPERSION EXCLUSION ZONE RESULTS COMPARISON

20 BUNKERING FACILITY VAPOR DISPERSION MODELING

20.1 Jetting and Flashing

The design spills used as the basis for jetting and flashing are detailed in Table 20.1-1.

Table 20.1-1: LNG Single Accidental Leakage Source

Spill Source (Scenario)	Failure Type	Line Size (inch)	Single Accidental Leakage Source (inch)
Rundown Line (B-1)	Pipe	2	Up to 2
Rundown Line (B-2)	Connection	1	1
Bunkering Line (B-3)	Pipe	6	Up to 6
Bunkering Line (B-4)	Connection	4	4
Bunkering Line (B-5)	Connection	3	3

Spill Source (Scenario)	Failure Type	Line Size (inch)	Single Accidental Leakage Source (inch)
Bunkering Line (B-6)	Connection	2	2
Bunkering Line (B-7)	Connection	1	1

Operating conditions, such as temperature, pressure, flow rate and release elevation used in the analysis are presented in Table 20.1-2. Pump runout flow conditions associated with depressurization during a release scenario have been considered where applicable.

Table 20.1-2: LNG Process Conditions

Spill Source (Scenario)	Operating Temp (°F)	Operating Pressure (psig)	Operating Mass Flow Rate (lb/hr)	Release Elevation (feet)
Rundown Line (B-1)	-260	50	15,505	3
Rundown Line (B-2)	-260	50	15,505	3
Bunkering Line (B-3)	-260	40	296,108	3
Bunkering Line (B-4)	-260	40	296,108	3
Bunkering Line (B-5)	-260	40	296,108	3
Bunkering Line (B-6)	-260	40	296,108	3
Bunkering Line (B-7)	-260	40	296,108	3

In addition to location and flow rate considerations used to determine the design spills to be analyzed for jetting and flashing, the worst-case jetting and flashing scenarios (Bounding Scenarios) for the SALS detailed in Table 20.1-2 will result from a hole size that results in the greatest total vapor mass flow rate. For SALS that are not downstream of an unlimited source (e.g. storage vessel), some depressurization of the line will occur until it reaches an equilibrium pressure. When a pressurized leak occurs, the liquid jet will atomize and, depending on the operating conditions and release elevation, a portion of the jet may rainout and pool on the ground. The total vapor mass flow rate is a combination of the vaporization rate from the flashing jet and the vaporization rate from the pool on the ground. Since the greatest total vapor mass flow rate associated with a single accidental leakage source may not occur at the largest hole size, PHAST was used to perform a sensitivity analysis on multiple hole sizes for pipe failures.

Table 20.1-3 presents the results of a sensitivity study for the scenarios to determine the Bounding Scenarios for pipe failures.

Table 20.1-3: Jetting and Flashing Sensitivity Study

Spill Source (Scenario)	Hole Size (inch)	Equilibrium Pressure (psig)	Rainout %	Release Vapor Mass Flow Rate (lb/hr)	Pool Vapor Mass Flow Rate (lb/hr)	Total Vapor Mass Flow Rate (lb/hr)
Rundown Line (B-1)	0.62	50	0	15,875	0	15,875
Bunkering Line (B-3)	2.84	40	26	297,942	67,690	287,000

Based on the sensitivity study detailed in Table 20.1-3 and the design spills determined for all hole sizes, Table 20.1-4 presents the worst-case scenarios to be modeled.

Table 20.1-4: Worst Case Scenarios

Spill Scenario	Location/Spill Source:	Hole Size (in)
B-1	Rundown Line	0.62
B-3	Bunkering Line	2.84

Figure 20.1-1 illustrates the release location for the worst-case scenarios described in Table 20.1-4:

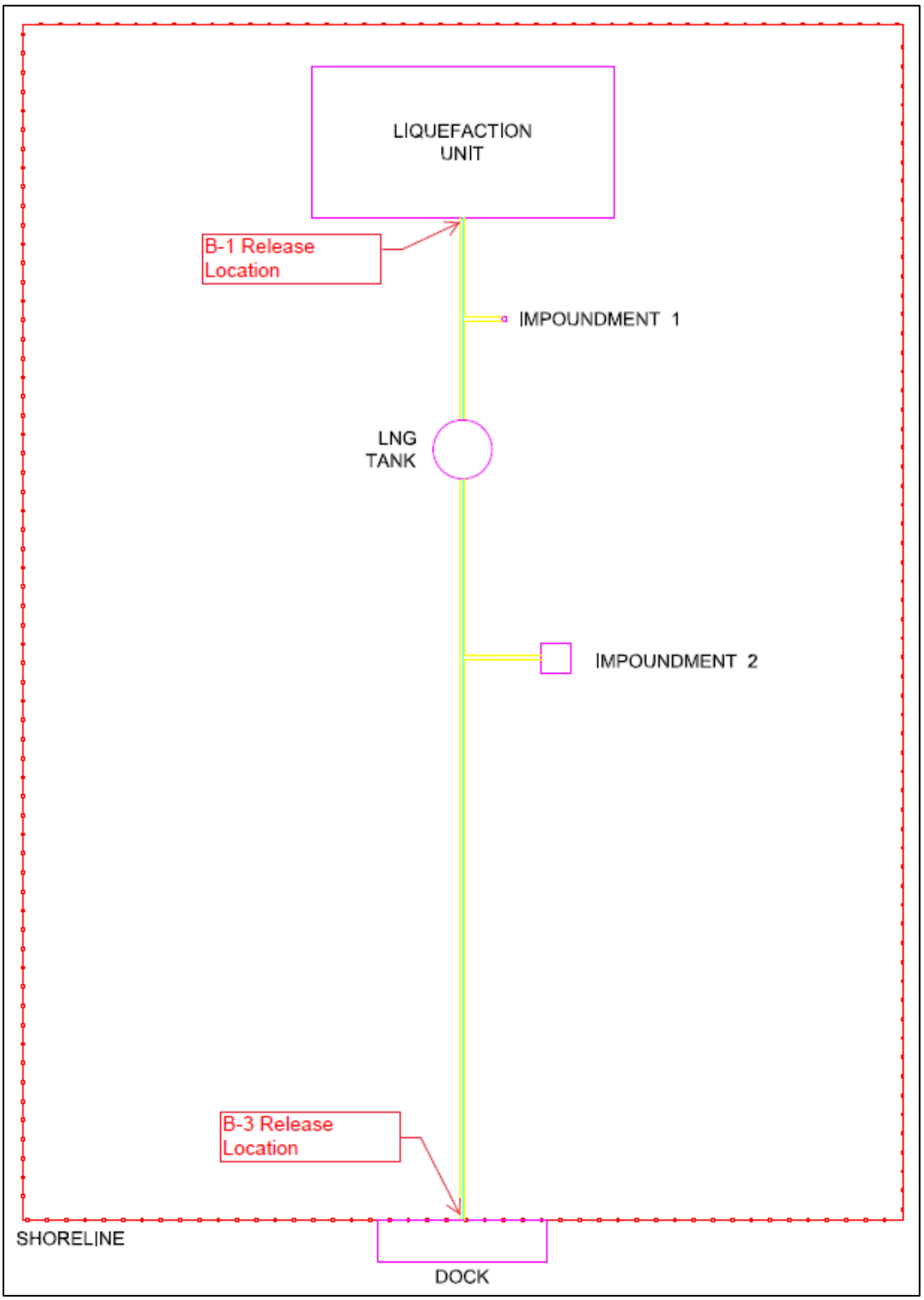

Figure 20.1-1: Jetting and Flashing Release Locations

The results of the modeling are included in Table 20.1-5.

Table 20.1-5: LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast Distance to ½ LFL (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)	FLACS Distance to ½ LFL (With Geometry) (ft)
B-1	2	0.03	345.11	367.45	Varies with direction
B-1	1	0.03	452.11	452.75	Varies with direction
B-1	2	0.01	404.02	N/A	Varies with direction
B-1	1	0.01	470.72	N/A	Varies with direction
B-3	2	0.03	1,274.02	2,198.16	Varies with direction
B-3	1	0.03	1,576.31	2,690.29	Varies with direction
B-3	2	0.01	1,612.56	N/A	Varies with direction
B-3	1	0.01	2,073.38	N/A	Varies with direction

The results of the jetting and flashing vapor dispersion modeling are illustrated in the following figures:

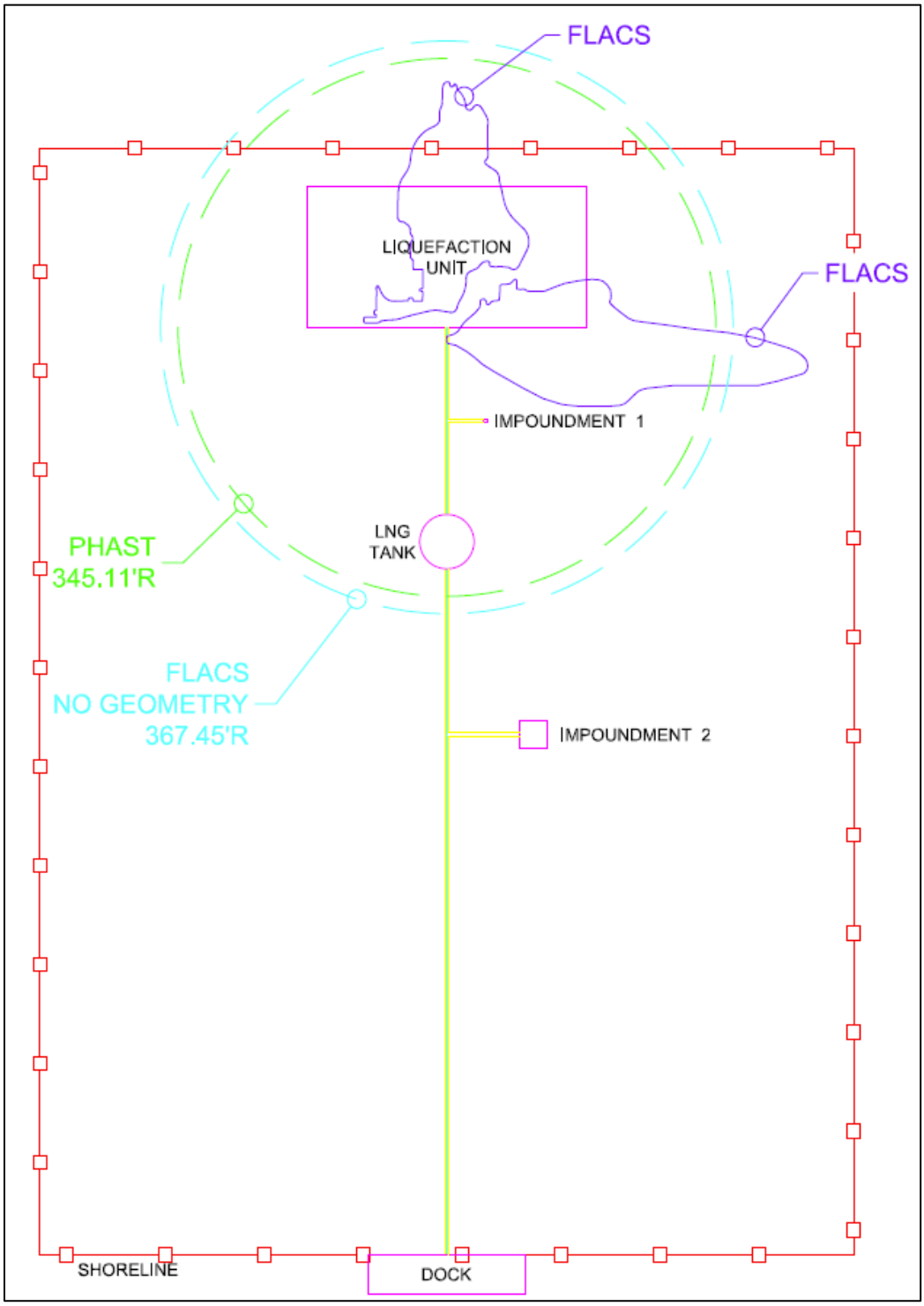

Figure 20.1-2: Rundown Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 20-2 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

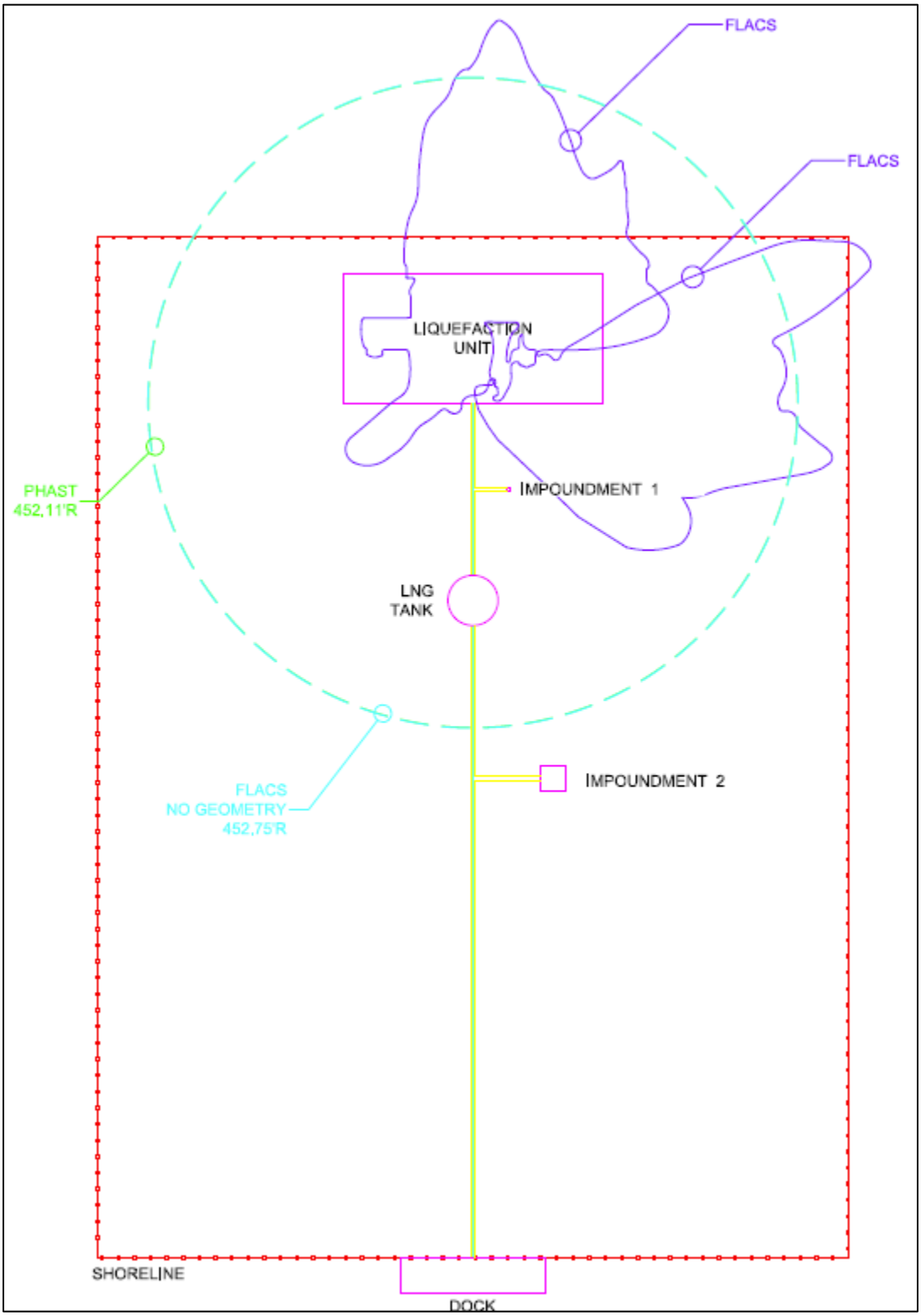

Figure 20.1-3: Rundown Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 20-3 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

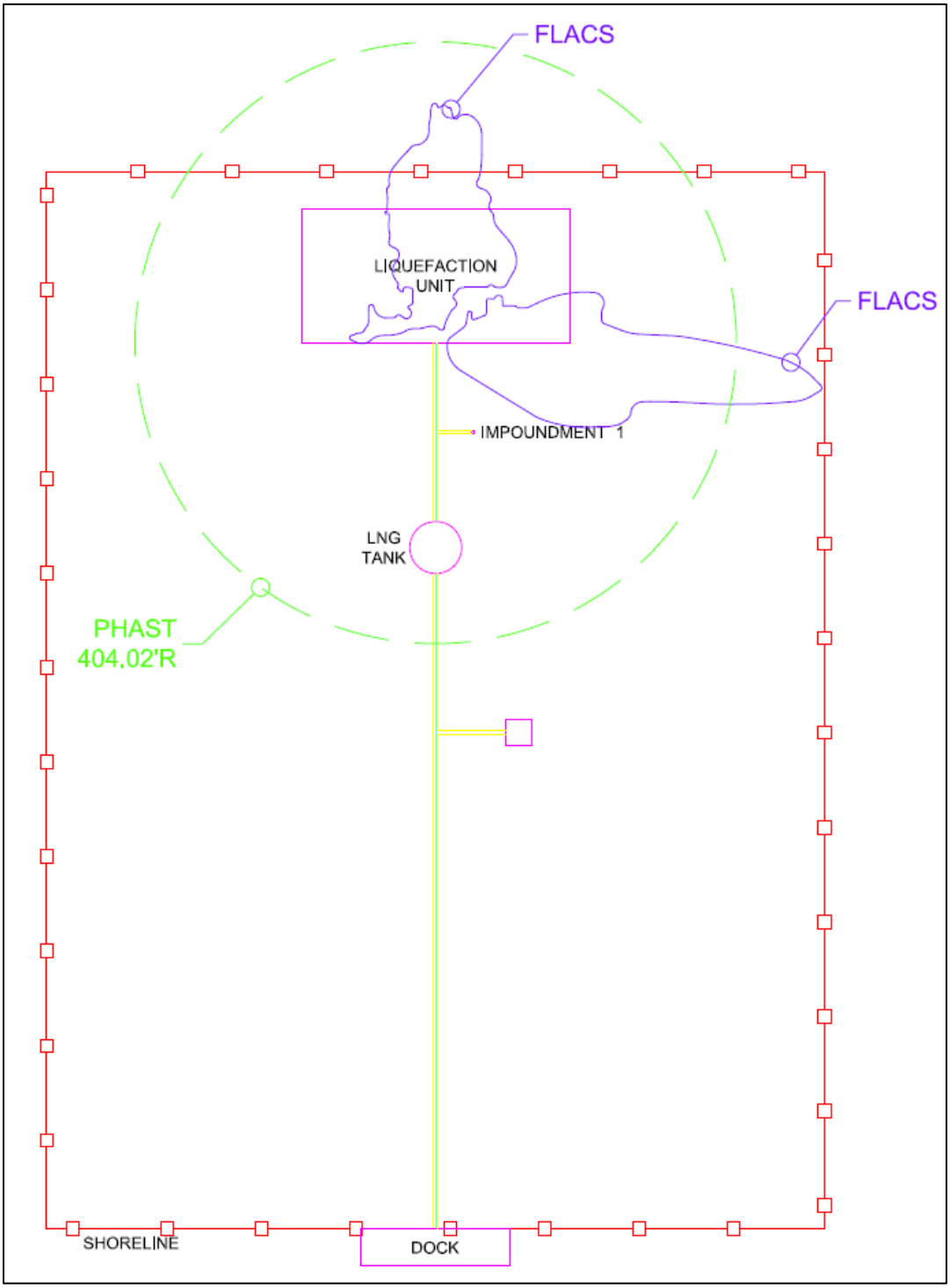

Figure 20.1-4: Rundown Line (2 m/s, 0.01m)

The FLACS results illustrated in Figure 20-4 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

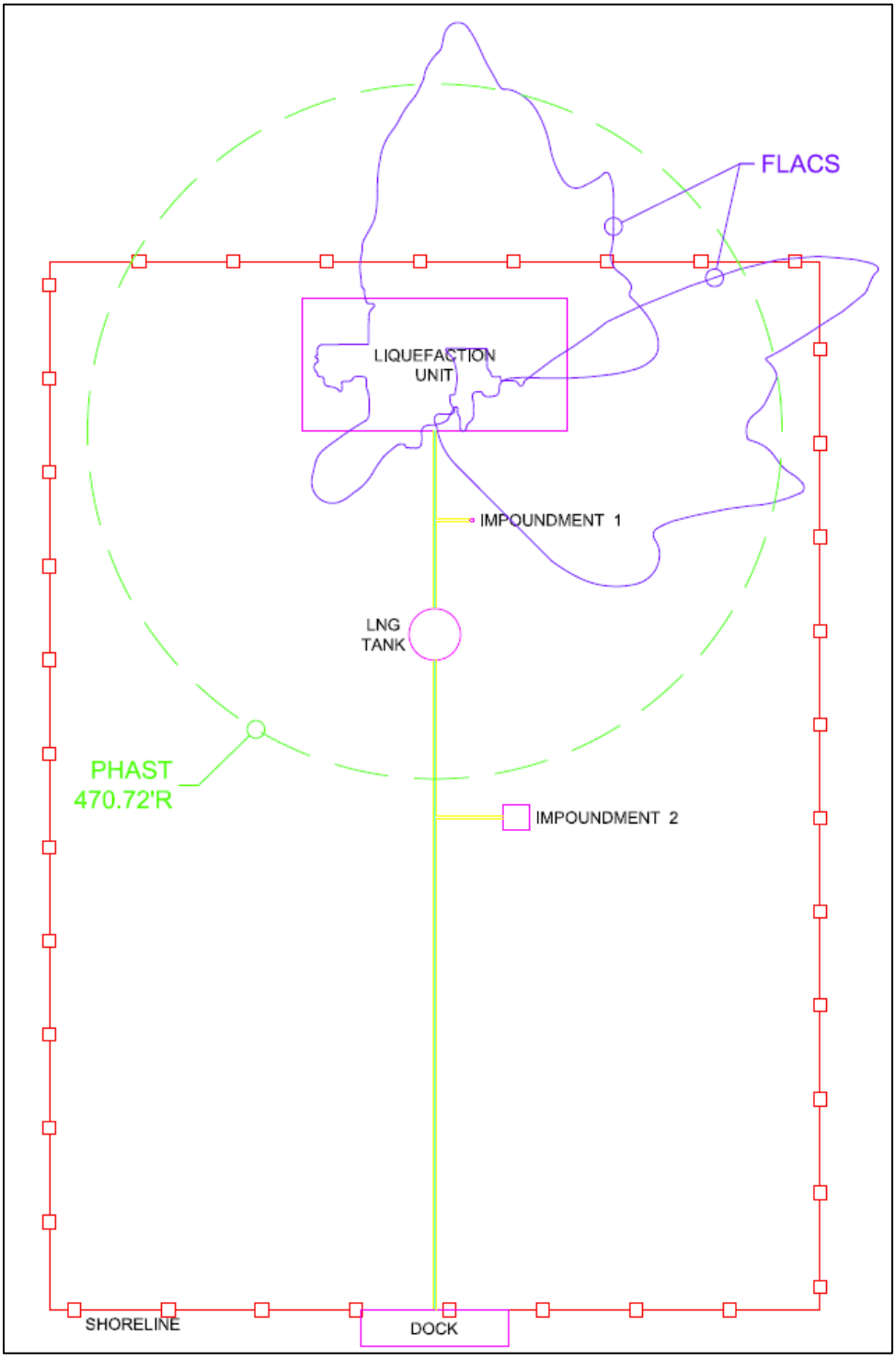

Figure 20.1-5: Rundown Line (1 m/s, 0.01m)

The FLACS results illustrated in Figure 20-5 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

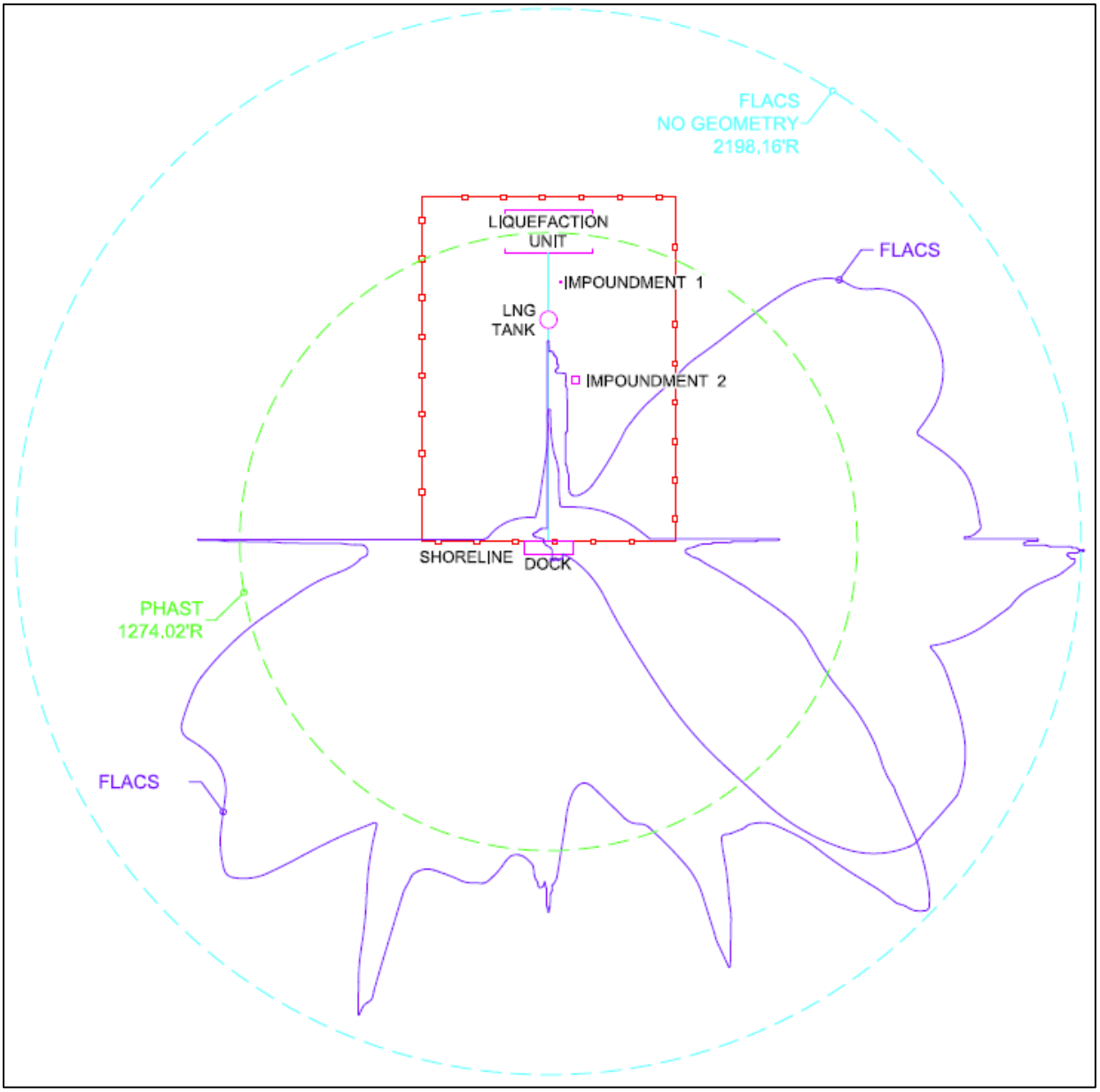

Figure 20.1-6: Bunkering Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 20-6 include (1) a release direction to the South with winds blowing to the South, Southwest and Southeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

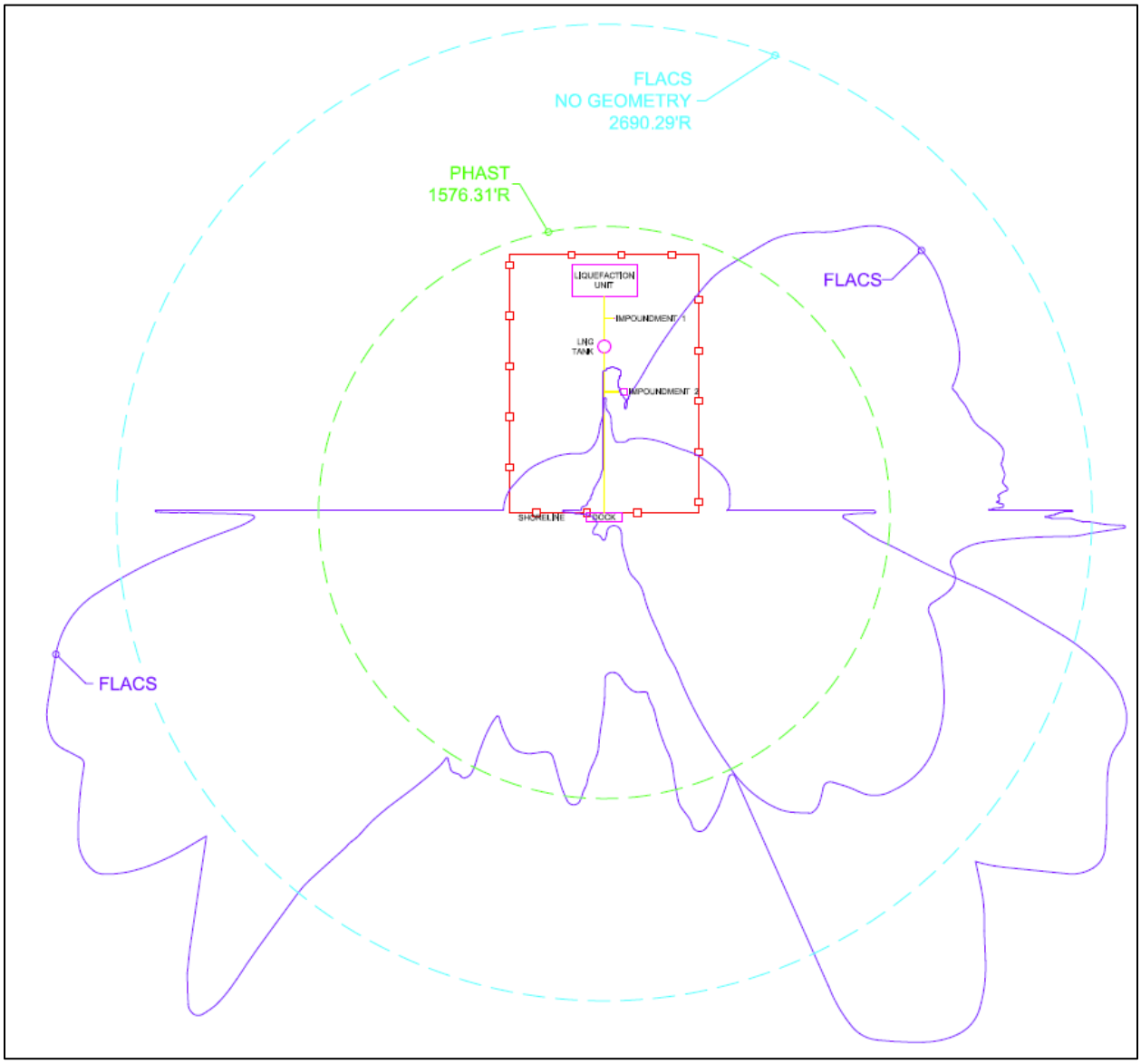

Figure 20.1-7: Bunkering Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 20-7 include (1) a release direction to the South with winds blowing to the South, Southwest and Southeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

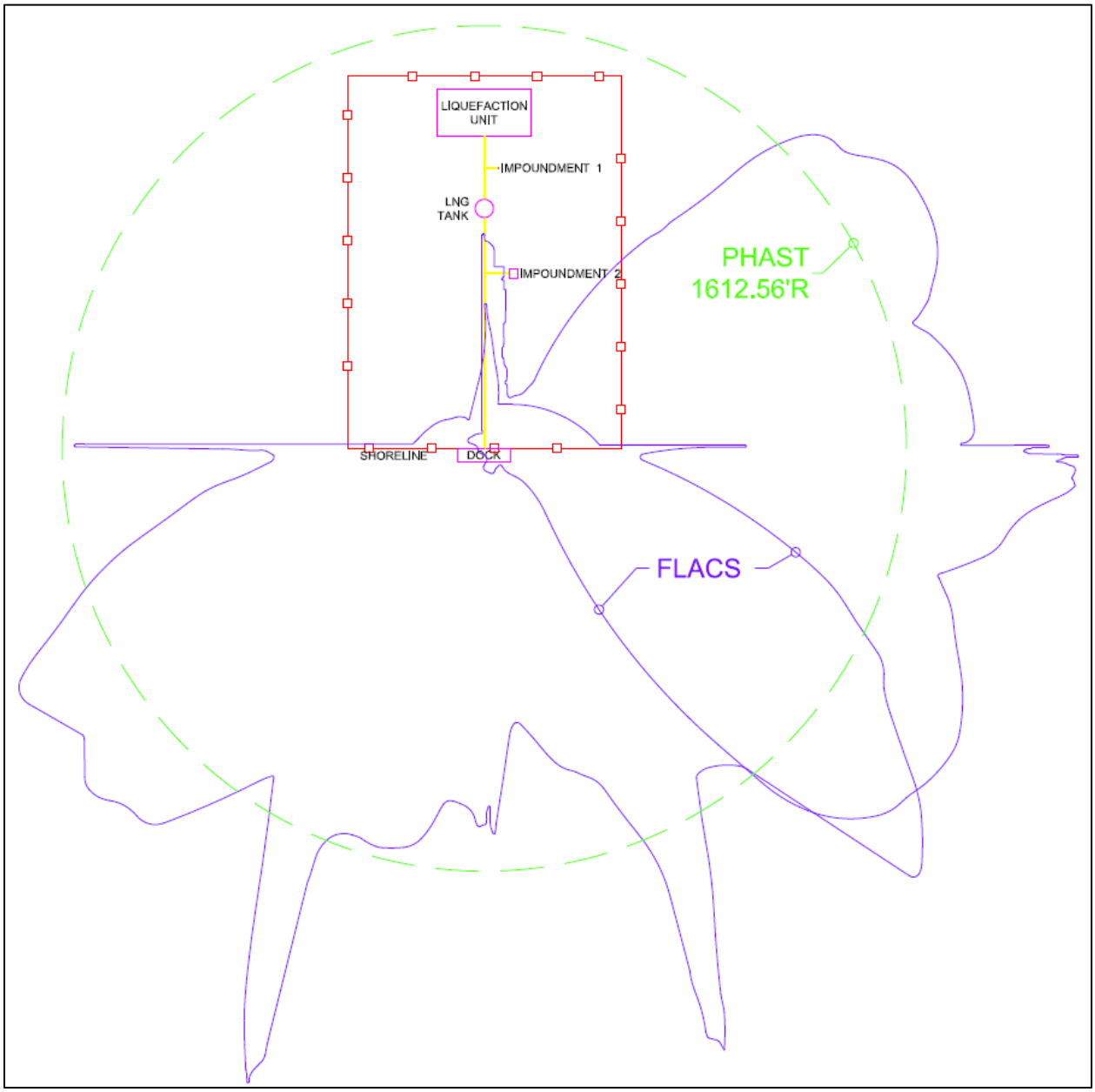

Figure 20.1-8: Bunkering Line (2 m/s, 0.01m)

The FLACS results illustrated in Figure 20-8 include (1) a release direction to the South with winds blowing to the South, Southwest and Southeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

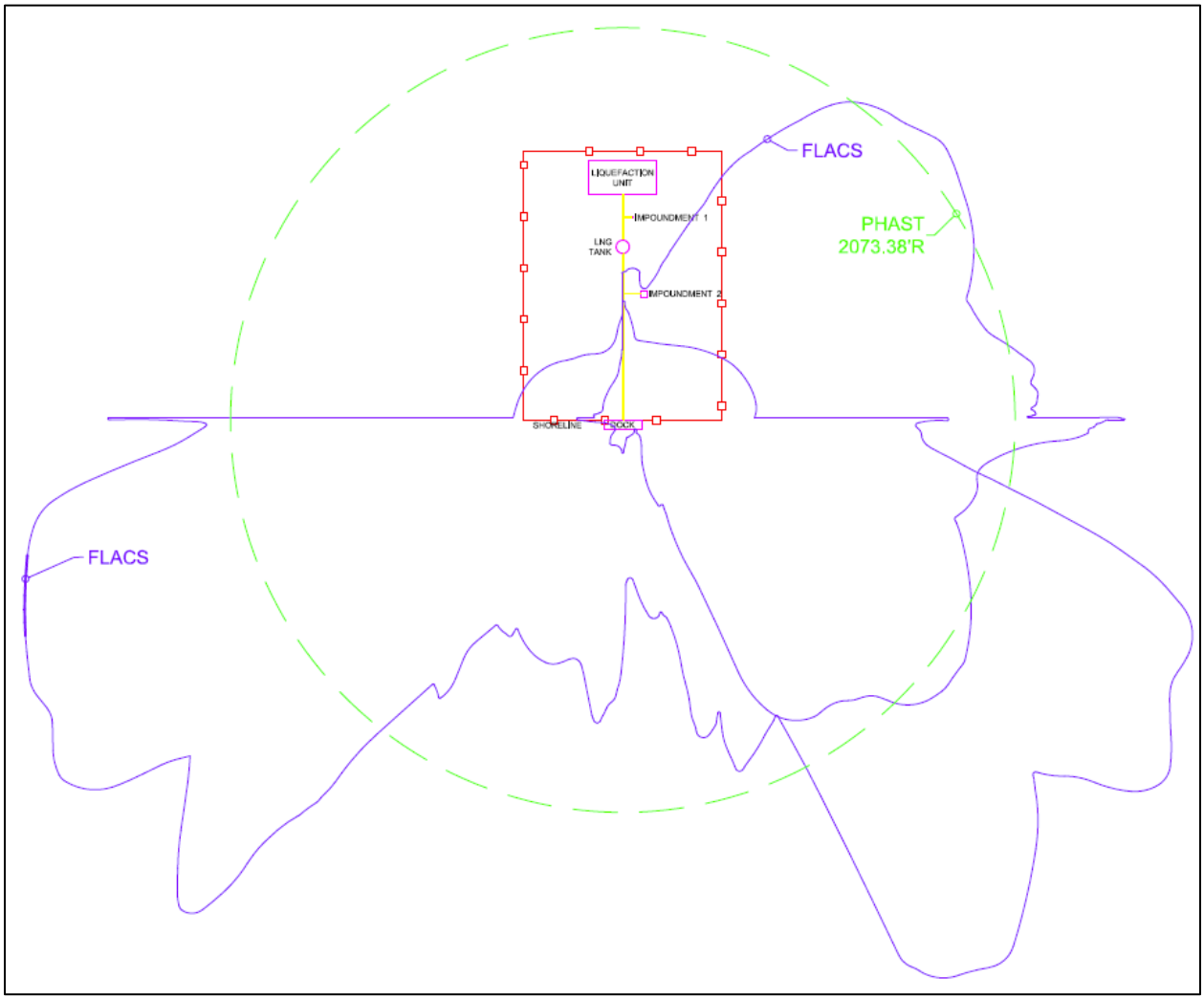

Figure 20.1-9: Bunkering Line (1 m/s, 0.01m)

The FLACS results illustrated in Figure 20-9 include (1) a release direction to the South with winds blowing to the South, Southwest and Southeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

Results Discussion:

For the rundown line, the results are comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are only slightly different between the Phast and FLACS model.

For the bunkering line, the results are comparable across the different models overall with variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 2 between the Phast and FLACS model.

20.2 LNG Conveyance

The design spills used as the basis for conveyance to impoundments are detailed in Table 20.2.

Table 20.2: LNG Conveyance Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10 Minute Spill Volume (ft^3)	Spill Containment Dimensions (ft x ft)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)
Rundown Line (B-1)	15,505	92.29	4 x 4	5 x 5 x 4	100
Bunkering Line (B-3)	296,108	1,762.5	4 x 4	35 x 35 x 2	2,450

Figure 20.2-1 illustrates the release location for the worst-case scenarios described in Table 20.2:

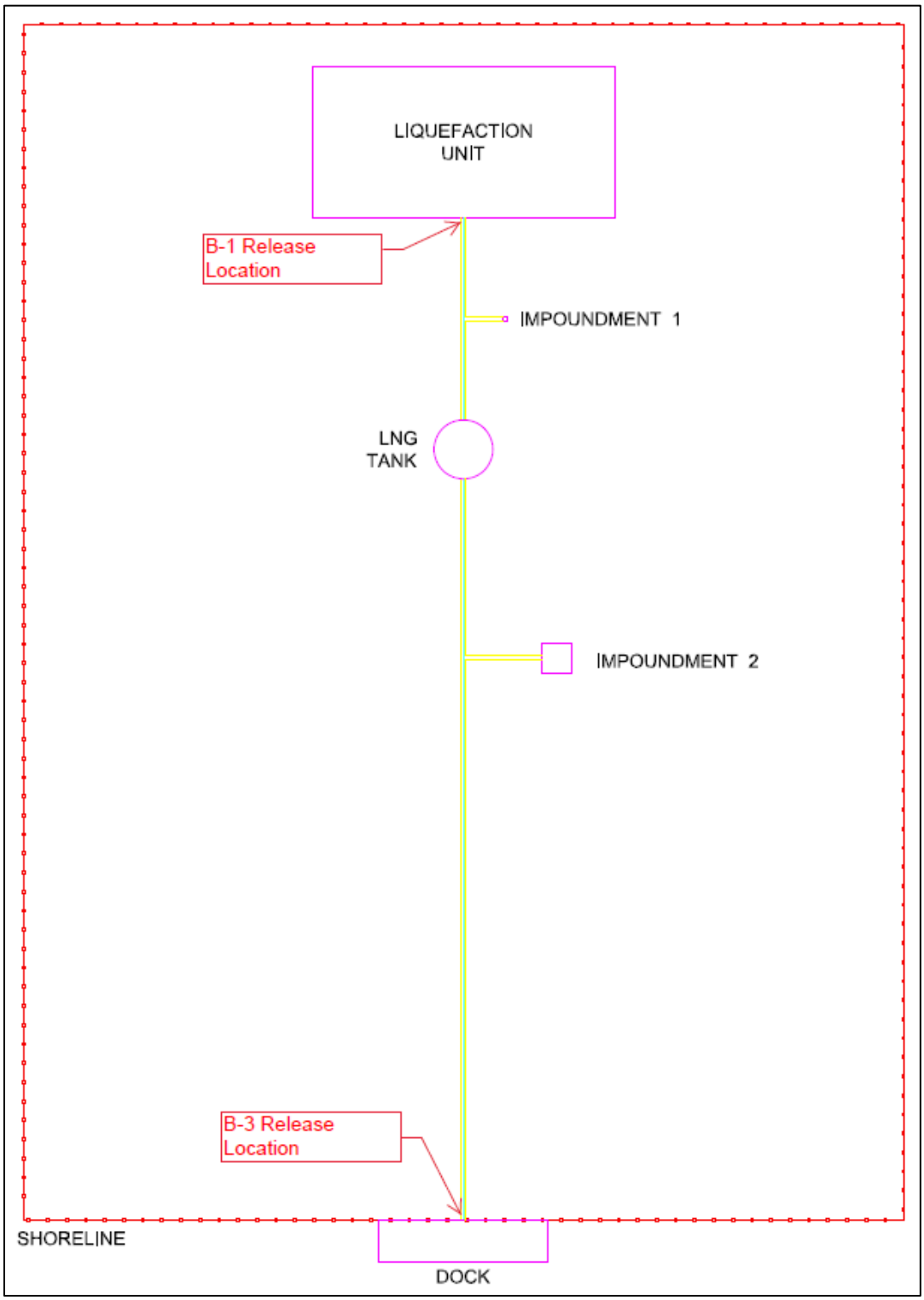

Figure 20.2-1: Conveyance Release Locations

All FLACS releases for LNG conveyance are for a release from the spill location as shown in figure 20.2-1 into the spill containment system flowing towards the impoundment. The results are presented in combined figures for winds blowing in the North, South, East, and West directions.

The results of the LNG conveyance to impoundment vapor dispersion modeling are illustrated in the following figures:

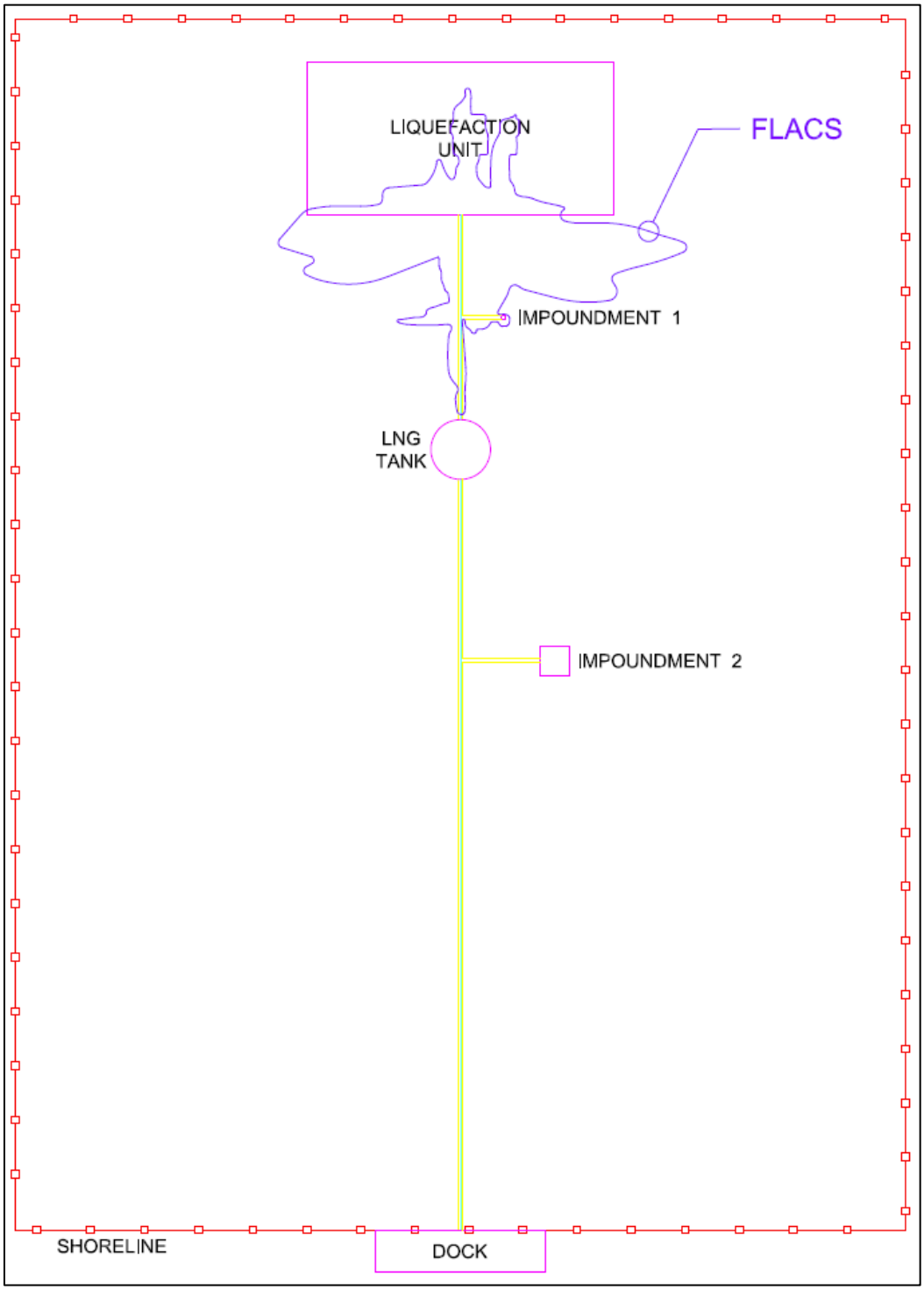

Figure 20.2-2: Rundown Line (2 m/s, 0.03 m)

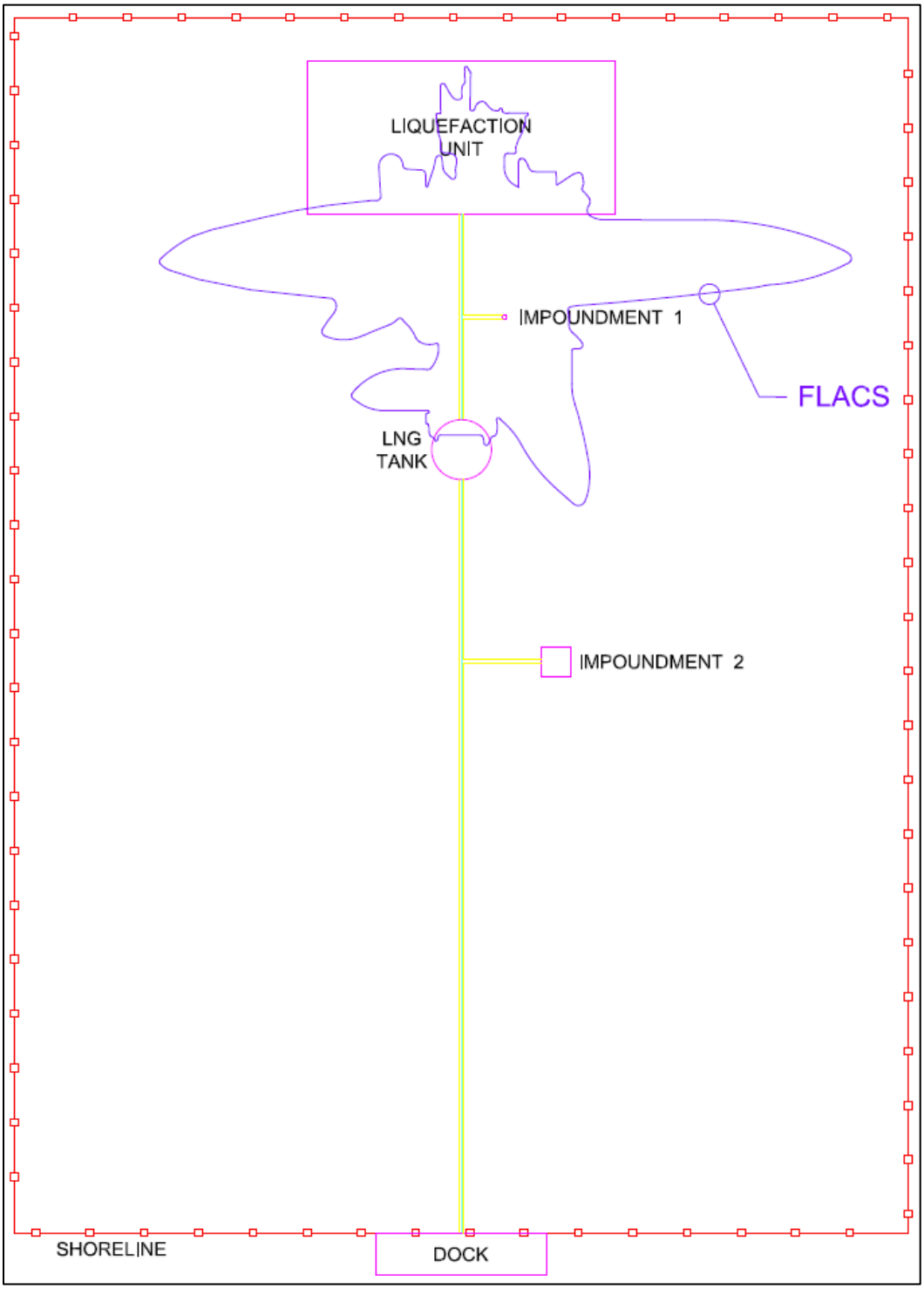

Figure 20.2-3: Rundown Line (1 m/s, 0.03m)

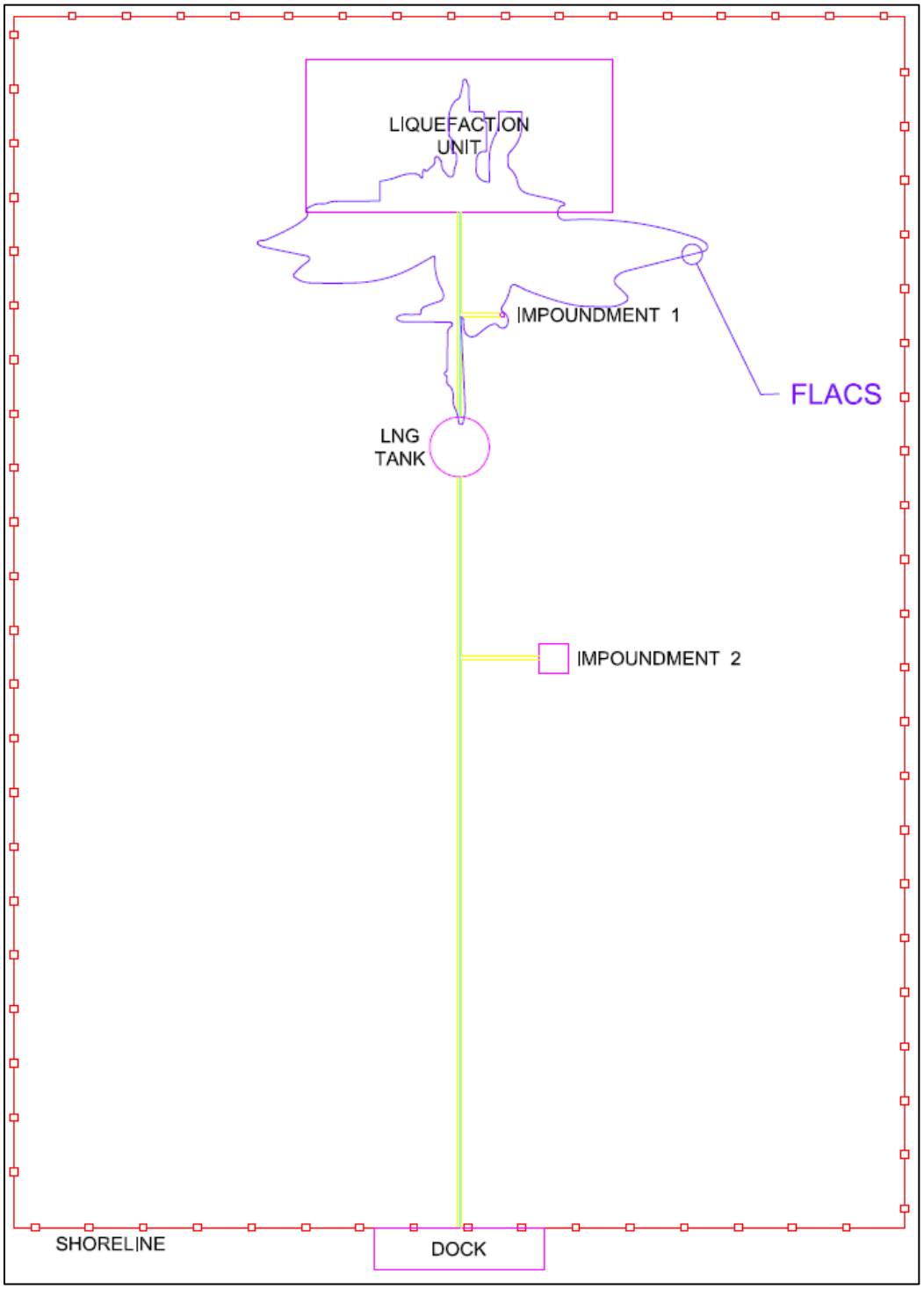

Figure 20.2-4: Rundown Line (2 m/s, 0.01m)

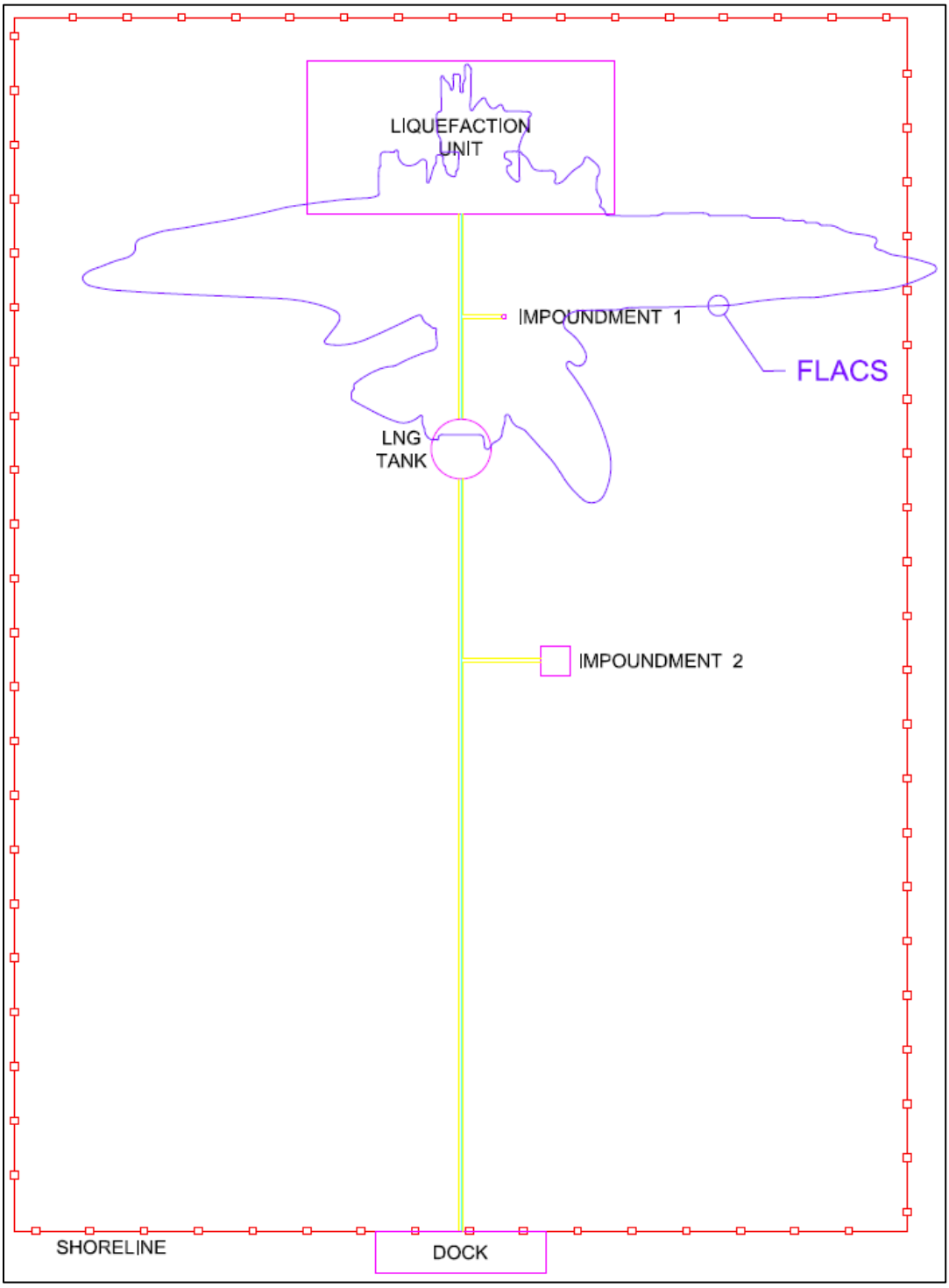

Figure 20.2-5: Rundown Line (1 m/s, 0.01m)

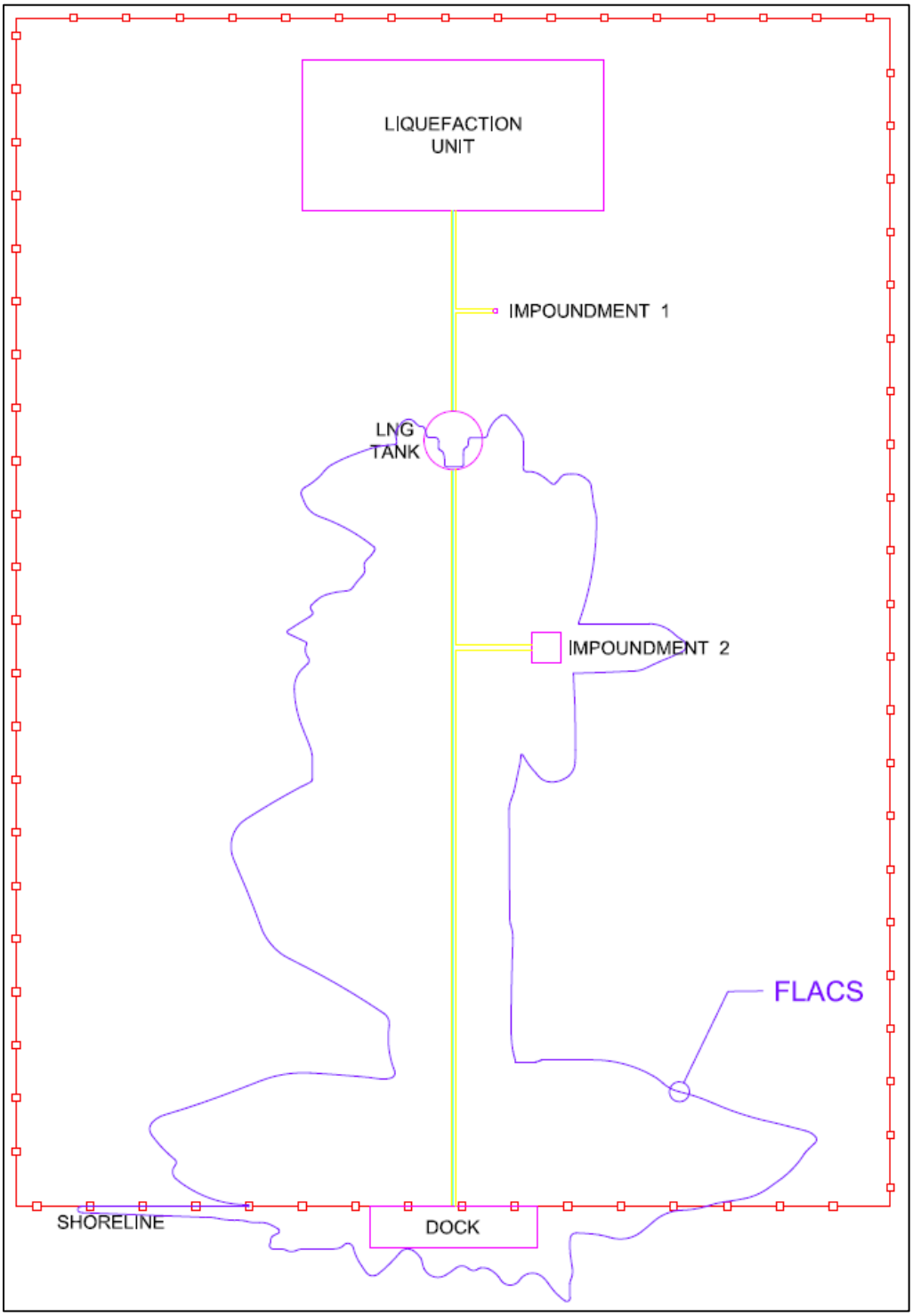

Figure 20.2-6: Bunkering Line (2 m/s, 0.03m)

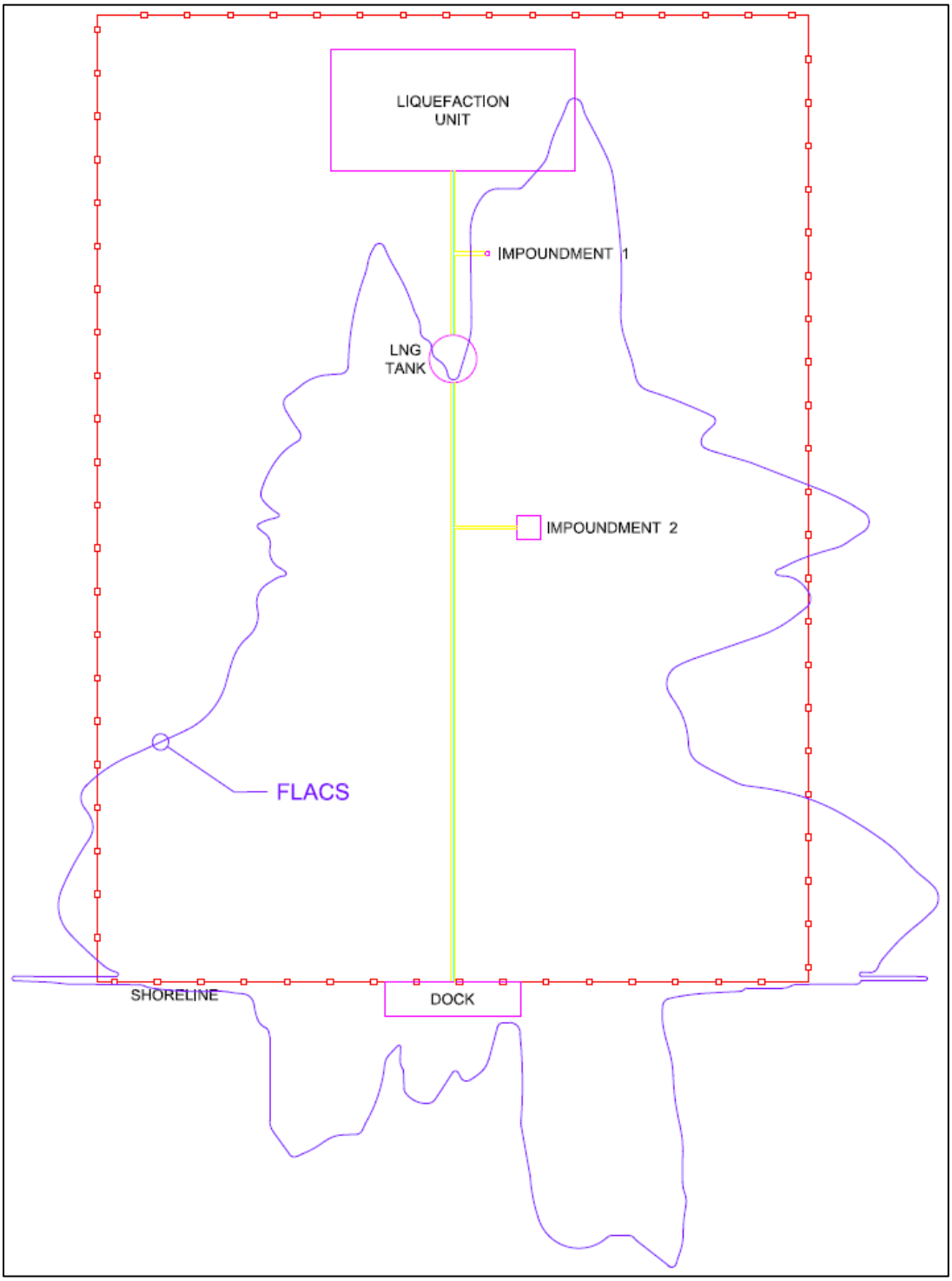

Figure 20.2-7: Bunkering Line (1 m/s, 0.03m)

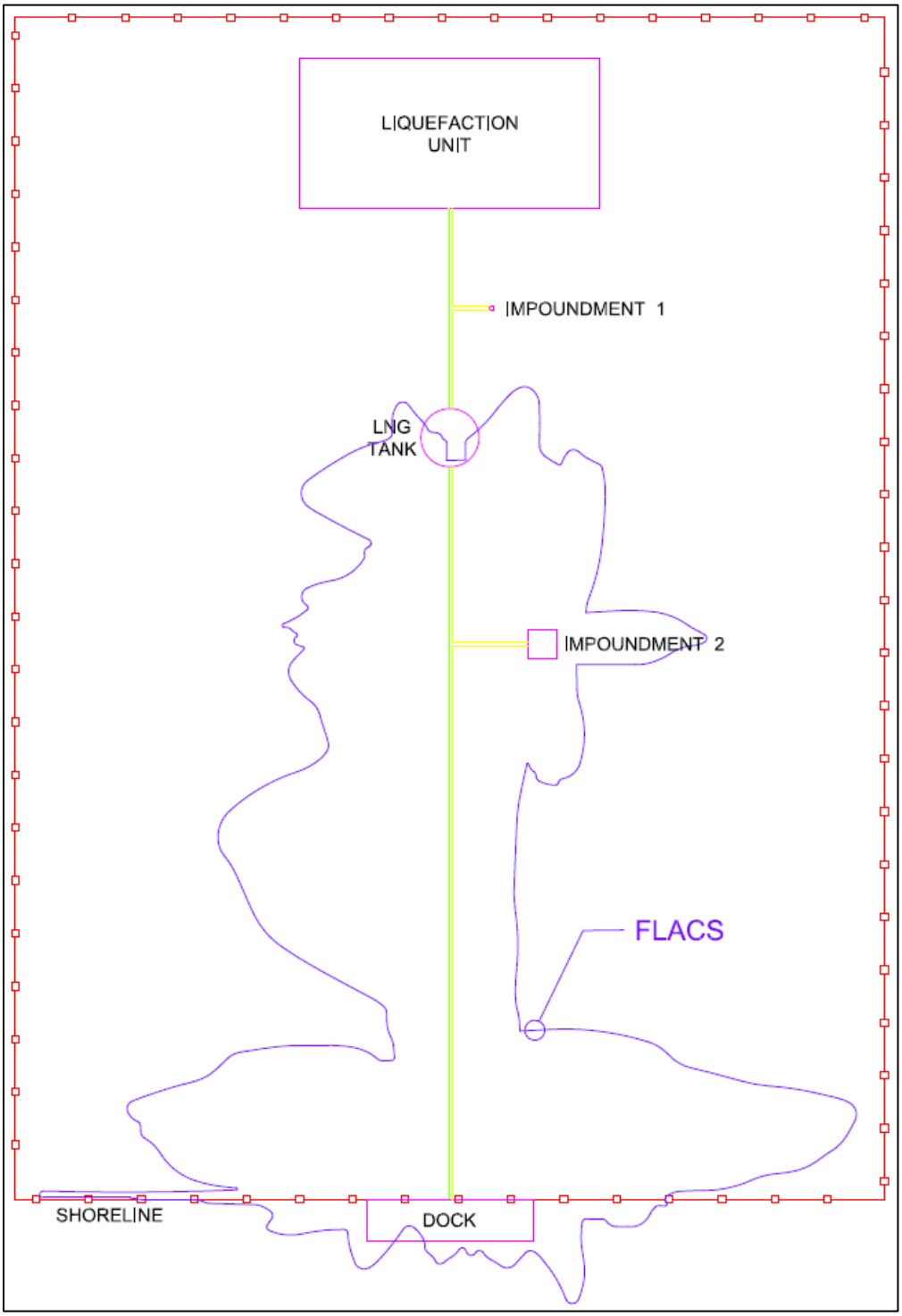

Figure 20.2-8: Bunkering Line (2 m/s, 0.01m)

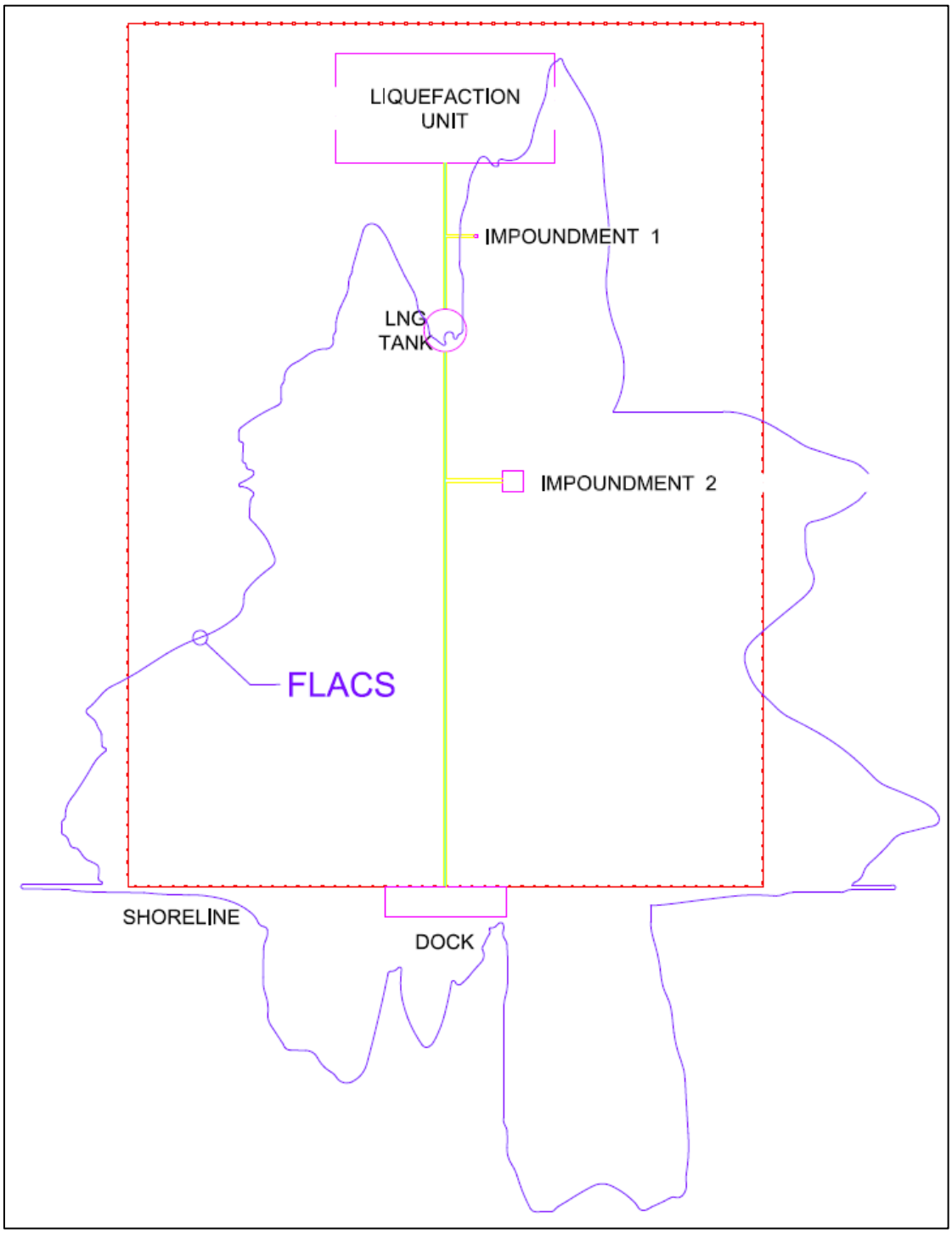

Figure 20.2-9: Bunkering Line (1 m/s, 0.01m)

Results Discussion:

The FLACS results illustrated in each figure for the different wind speed and surface roughness values are for a single release into the spill containment system, which flows into the impoundment basin. The results presented are combined results for winds blowing in the North, South, East and West directions.

The majority of the releases stay within the plant property line. The releases that extend beyond the facility property line can be mitigated with simple design optimizations.

All conveyance scenarios have smaller vapor dispersion exclusion zones compared to the jetting and flashing exclusion zones.

20.3 LNG Impoundments

The design spills used as the basis for LNG spills into impoundments are detailed in Table 20.3-1.

Table 20.3-1: LNG Impoundments Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10 Minute Spill Volume (ft^3)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)	Impoundment #
Rundown Line (B-1)	15,505	92.29	5 x 5 x 4	100	1
Bunkering Line (B-3)	296,108	1,762.5	35 x 35 x 2	2,450	2

Figure 20.3-1 illustrates the release location for the worst-case scenarios described in Table 20.3-1:

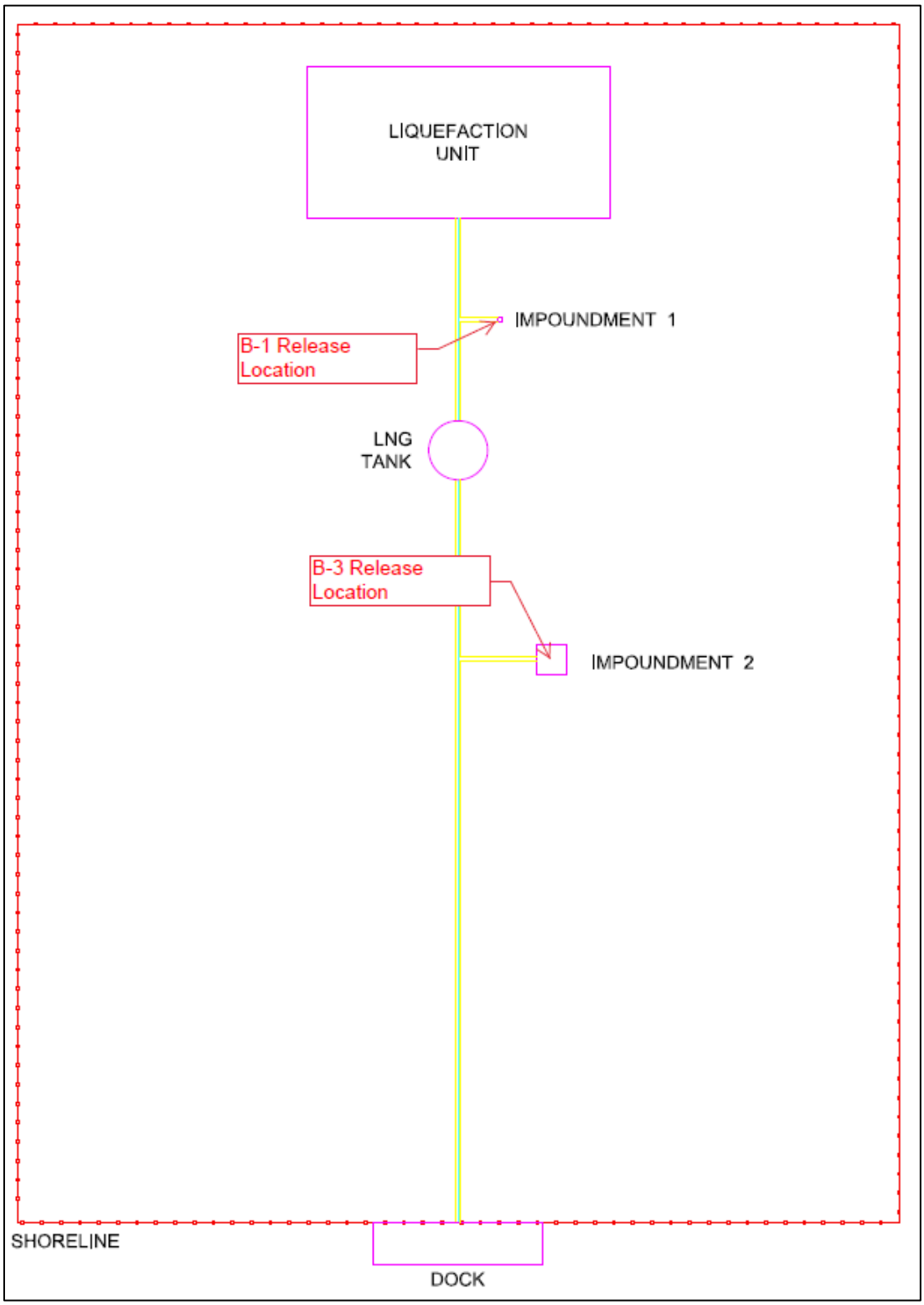

Figure 20.3-1: Impoundment Release Locations

The results of the LNG impoundment vapor dispersion modeling are detailed in Table 20.3-2.

Table 20.3-2: LNG Impoundments Vapor Dispersion Results

Spill Source (Scenario)	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast ½ LFL Distance (ft)	DEGADIS ½ LFL Distance (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)
Rundown Line (B-1)	2	0.03	242.31	96.99	118.11
Rundown Line (B-1)	1	0.03	331.13	88.31	147.64
Rundown Line (B-1)	2	0.01	267.67	106.18	N/A
Rundown Line (B-1)	1	0.01	380.42	103.51	N/A
Bunkering Line (B-3)	2	0.03	1,849.74	747.87	141.08
Bunkering Line (B-3)	1	0.03	2,323.74	737.62	278.87
Bunkering Line (B-3)	2	0.01	2,038.5	831.38	N/A
Bunkering Line (B-3)	1	0.01	2,578.77	760.37	N/A

The results of the LNG impoundment vapor dispersion modeling are illustrated in the following figures:

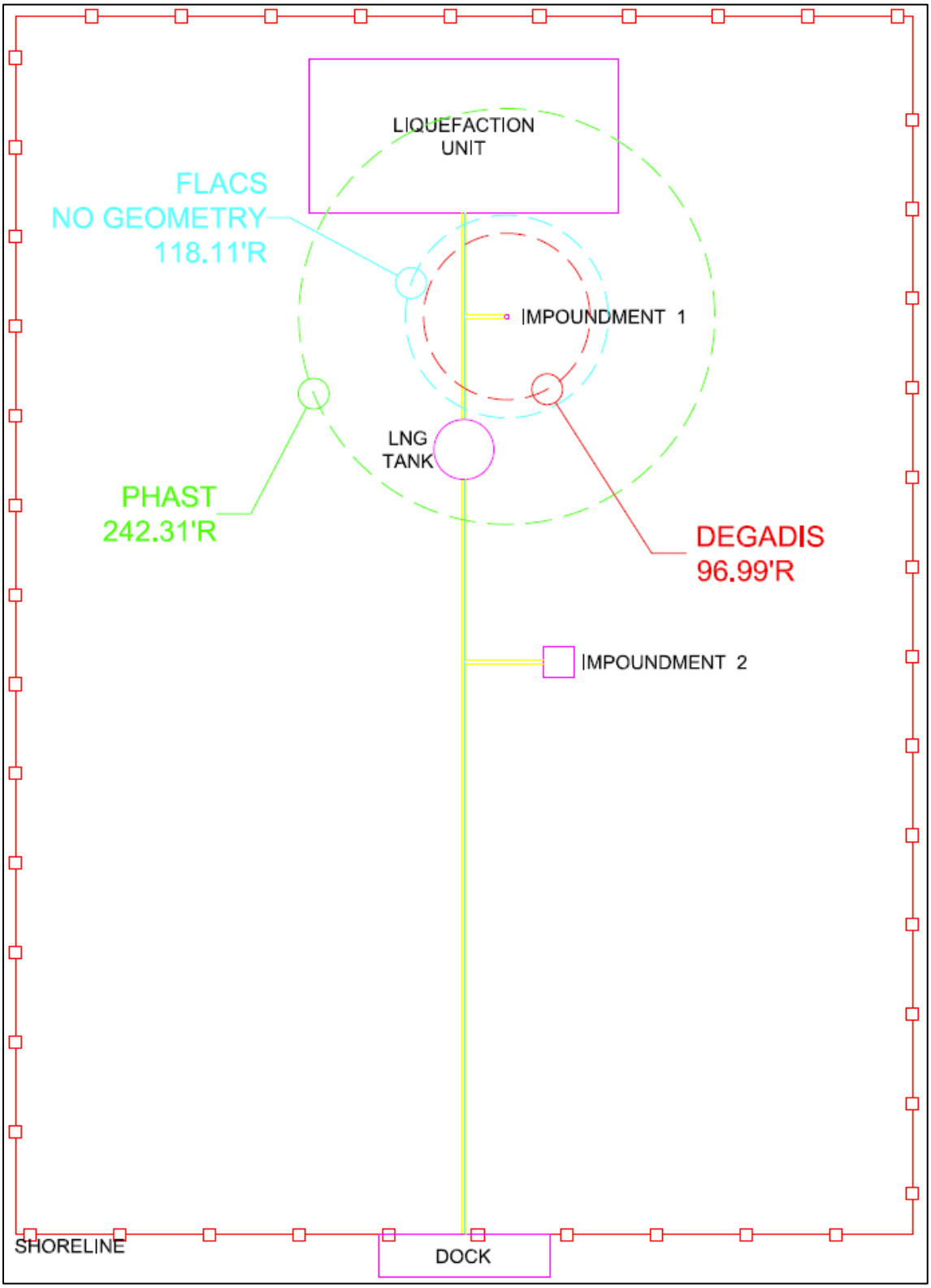

Figure 20.3-2: Rundown Line (2 m/s, 0.03m)

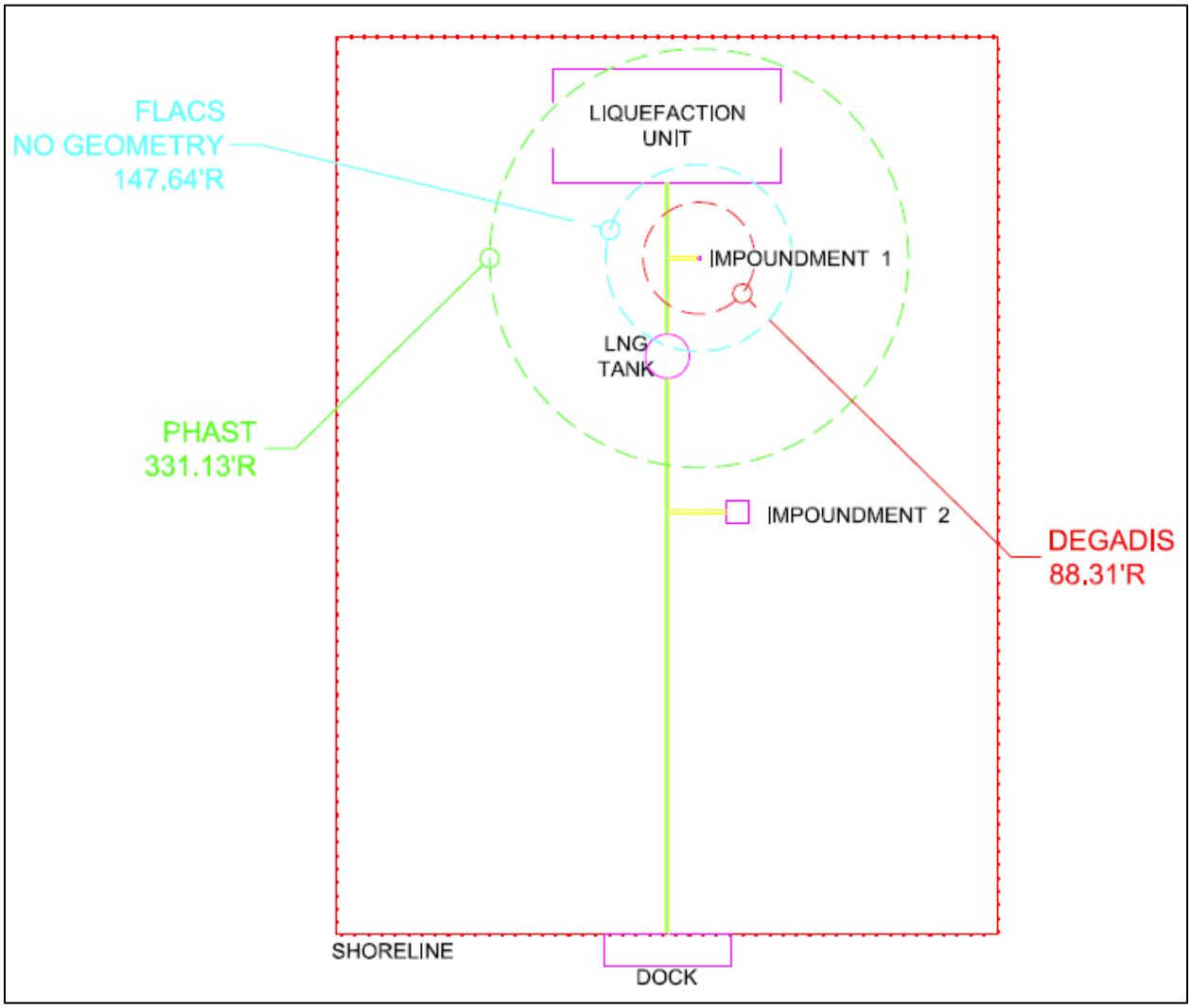

Figure 20.3-3: Rundown Line (1 m/s, 0.03m)

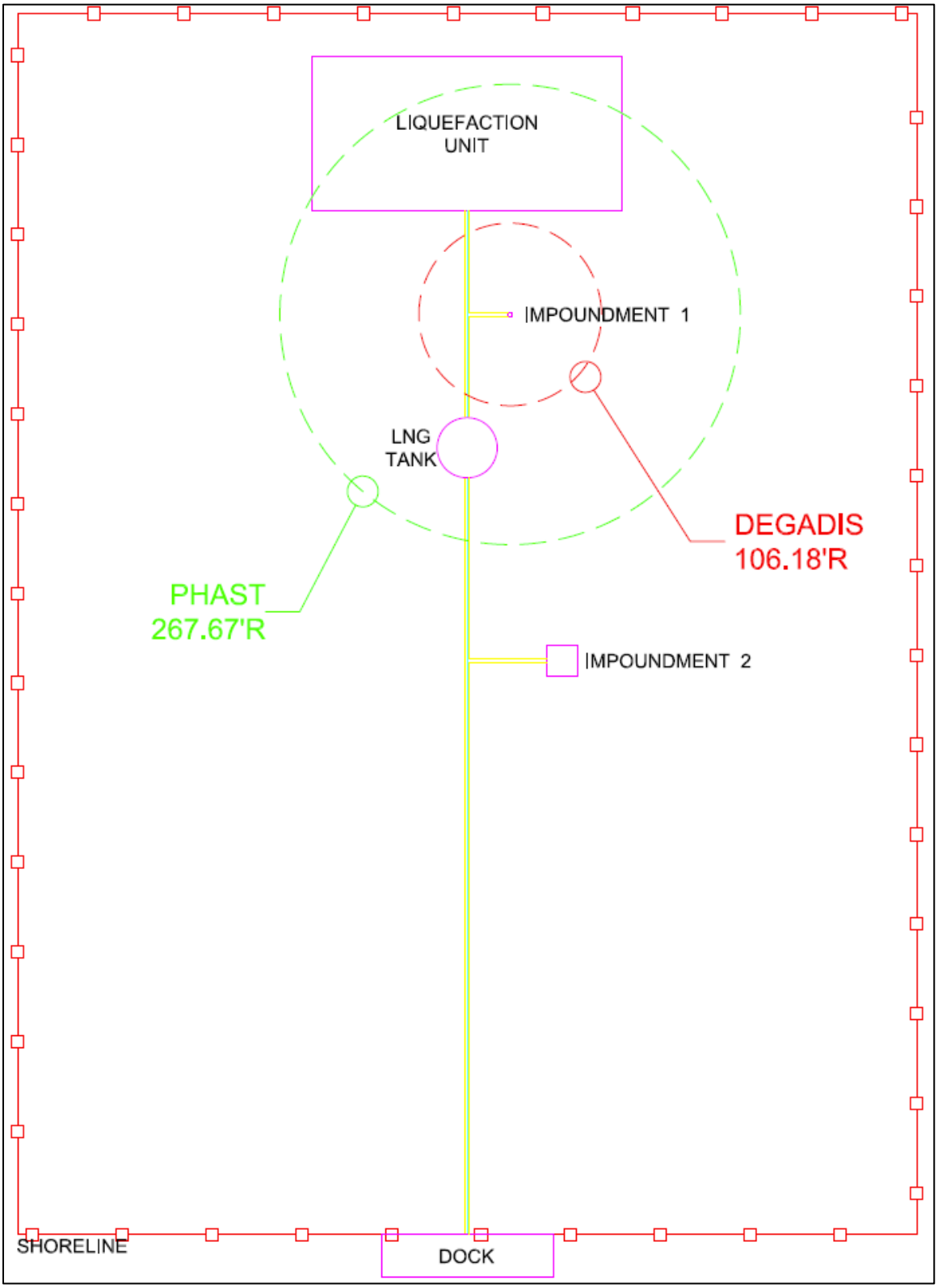

Figure 20.3-4: Rundown Line (2 m/s, 0.01m)

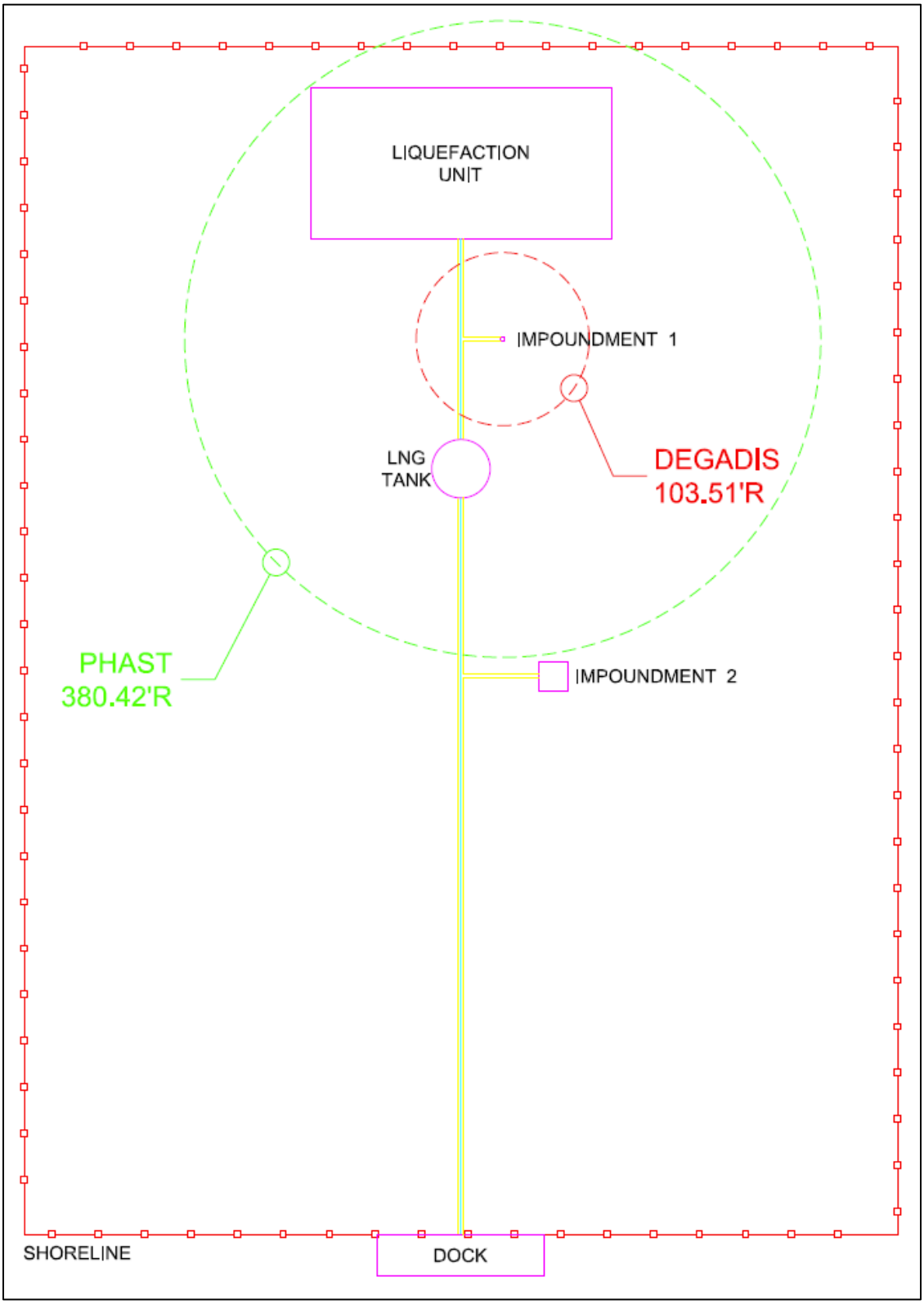

Figure 20.3-5: Rundown Line (1 m/s, 0.01m)

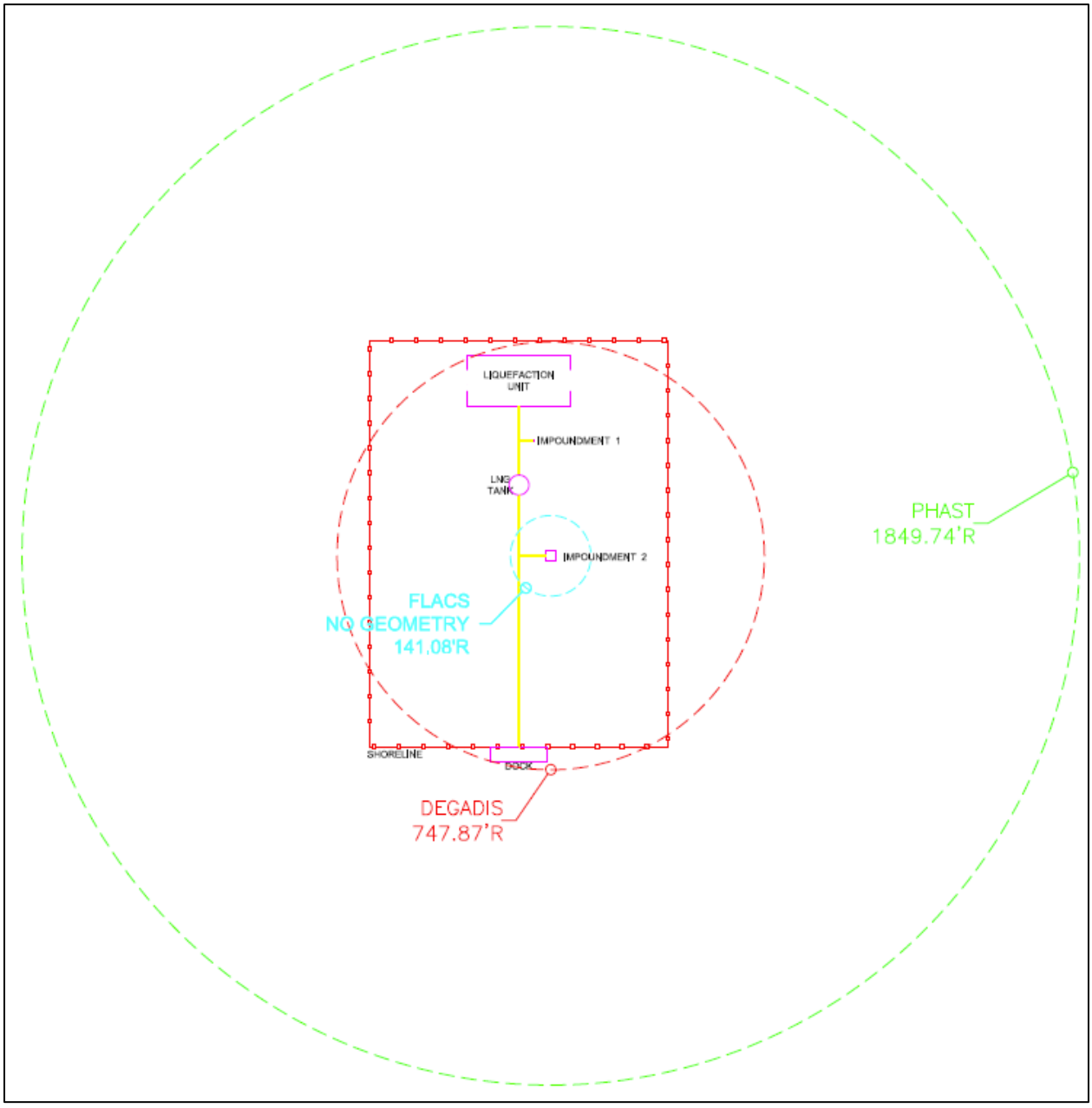

Figure 20.3-6: Bunkering Line (2 m/s, 0.03m)

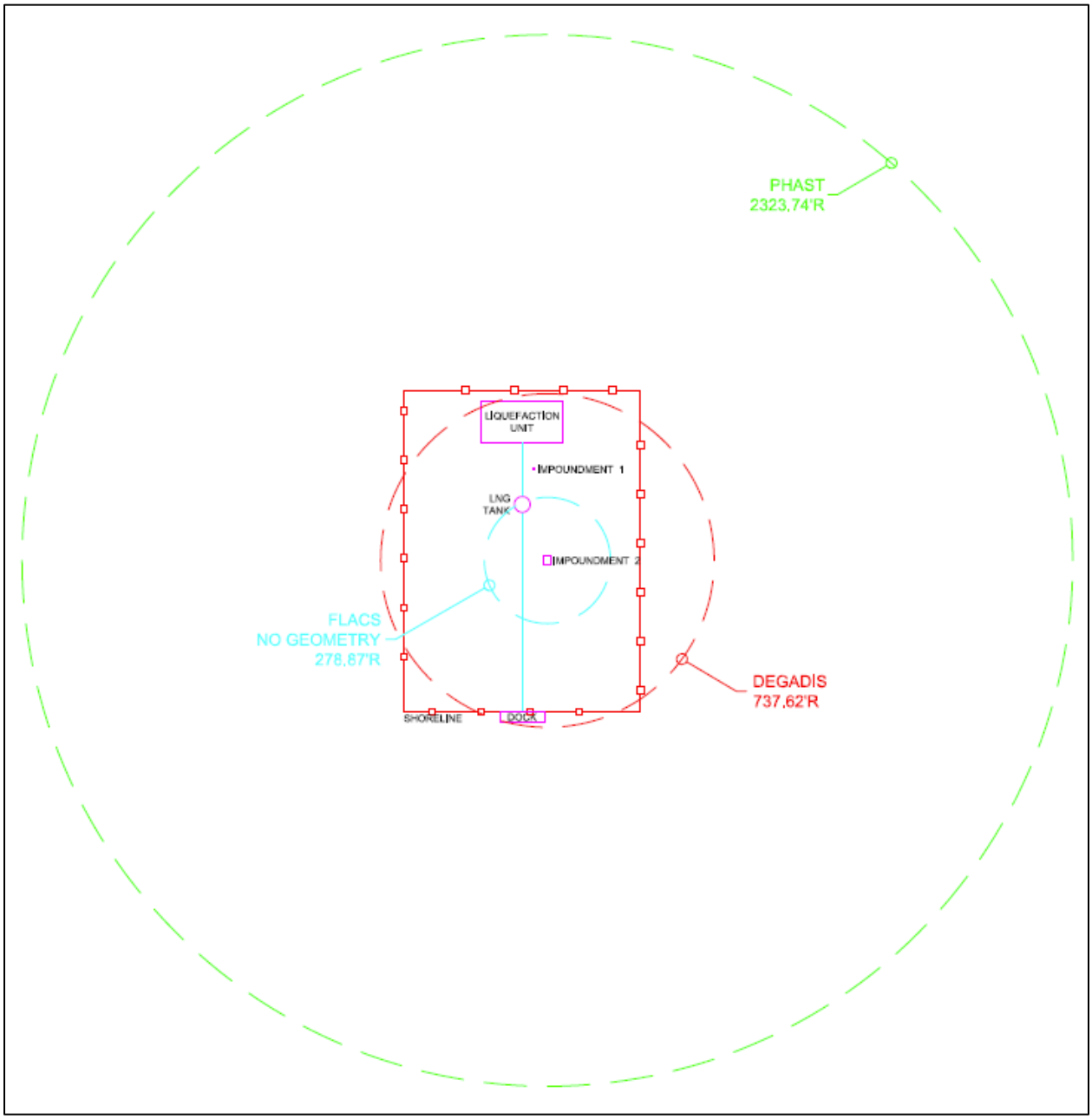

Figure 20.3-7: Bunkering Line (1 m/s, 0.03m)

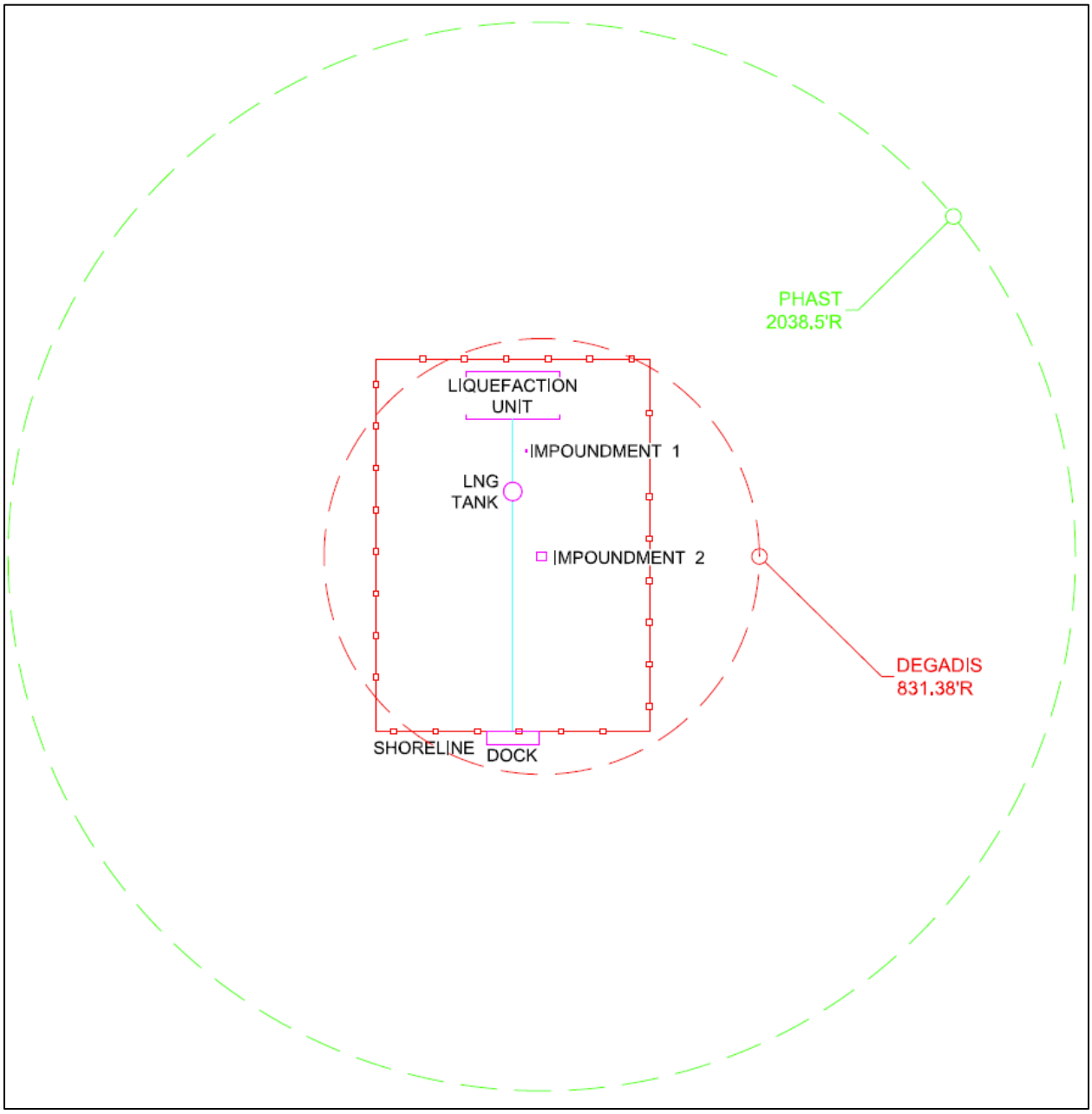

Figure 20.3-8: Bunkering Line (2 m/s, 0.01m)

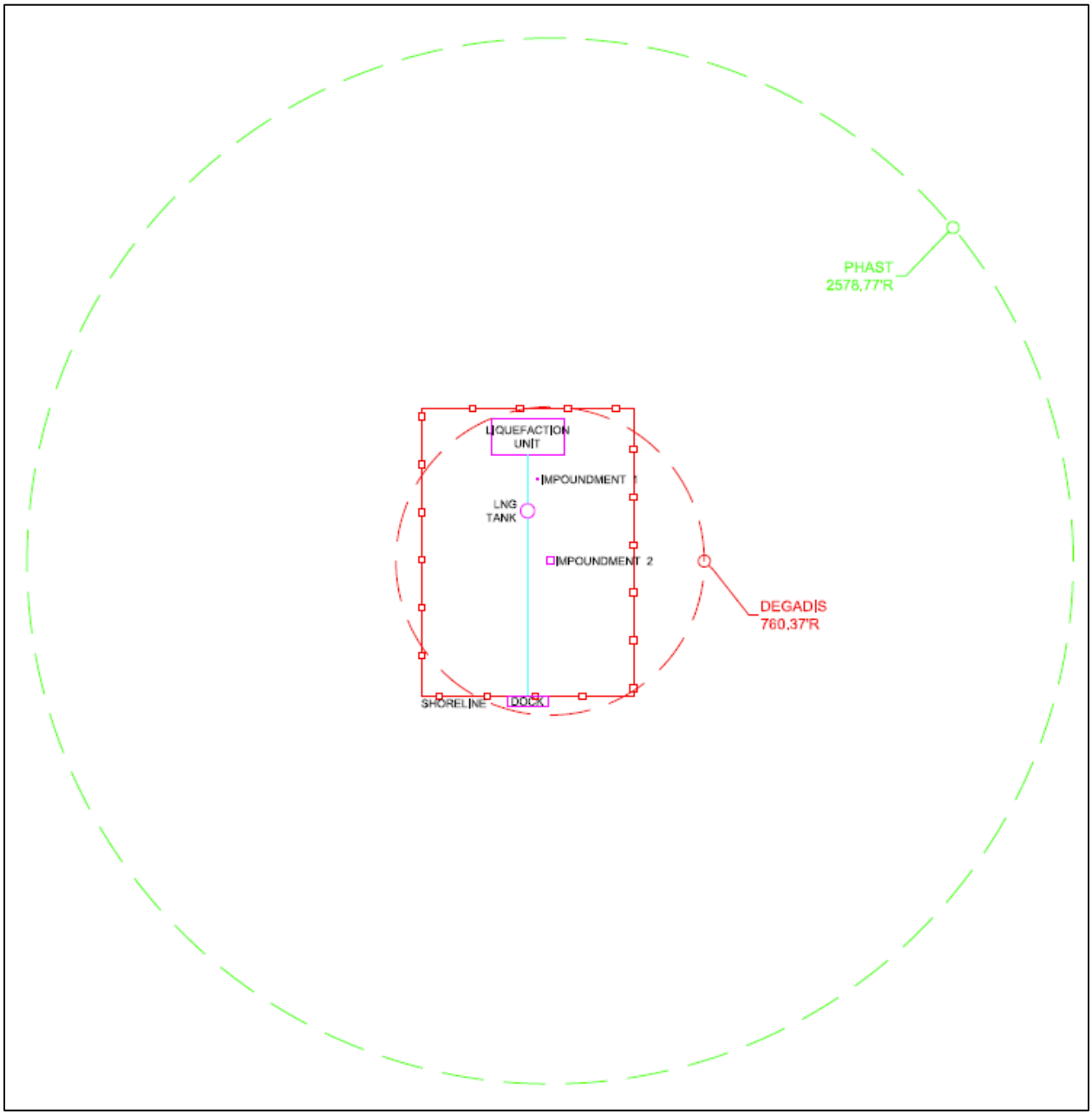

Figure 20.3-9: Bunkering Line (1 m/s, 0.01m)

Results Discussion:

The results for both impoundments have the FLACS (without geometry) and DEGADIS models providing generally comparable results and the Phast model providing vapor dispersion predictions greater than the FLACS and DEGADIS model. The results are within a factor of 2-3 between the Phast, FLACS and DEGADIS models.

The FLACS model can take into account the depth of the impoundment, which can provide additional vapor holdup. The Phast model does not account for the depth of the impoundment, and therefore the FLACS results will be more representative. Therefore, the results are as expected.

For Phast and FLACS, the properties of regular concrete were used for the impoundment modeling. Use of insulating concrete and its properties would reduce the vapor dispersion distances.

The majority of the releases stay within the plant property line. The releases that extend beyond the facility property line can be mitigated with basic design optimizations.

All impoundment scenarios have smaller vapor dispersion exclusion zones compared to the jetting and flashing scenarios due to the high pressure release associated with jetting and flashing mechanism described in section 6 of this Report.

20.4 Overall Exclusion Zone

The overall exclusion zone for the facility is best represented by the FLACS model as that model can account for facility specifics, including: spill containment systems, process equipment, LNG tanks, piperacks, terrain and other facility geometric features. For the jetting and flashing, conveyance and impoundment modeling performed for the bunkering facility, the overall exclusion zone is bounded by the jetting and flashing modeling as the extent of the jetting and flashing exclusion zones are further than the LNG conveyance and LNG impoundment exclusion zones. Jetting and flashing releases are modeled as a horizontal release directed towards the nearest property line therefore have high initial momentum towards the property line. This momentum and release orientation results in the jetting and flashing releases traveling further than the LNG conveyance or LNG impoundment vapor dispersion releases.

For the rundown line, it is likely that with layout optimization and mitigation the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration.

For the bunkering line, it is unlikely that with layout optimization and basic mitigation the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The 6 inch full guillotine failure of the bunkering line results in a very large spill which may be problematic for smaller bunkering facilities. This will require mitigation to maintain this spill within a property line.

Therefore, mitigation measures such as ESD and vapor fences will need to be considered to reduce the associated dispersion distances. Mitigation modeling is evaluated further in Section 27 of this Report.

The overall exclusion zone is illustrated in Figure 20.4 below:

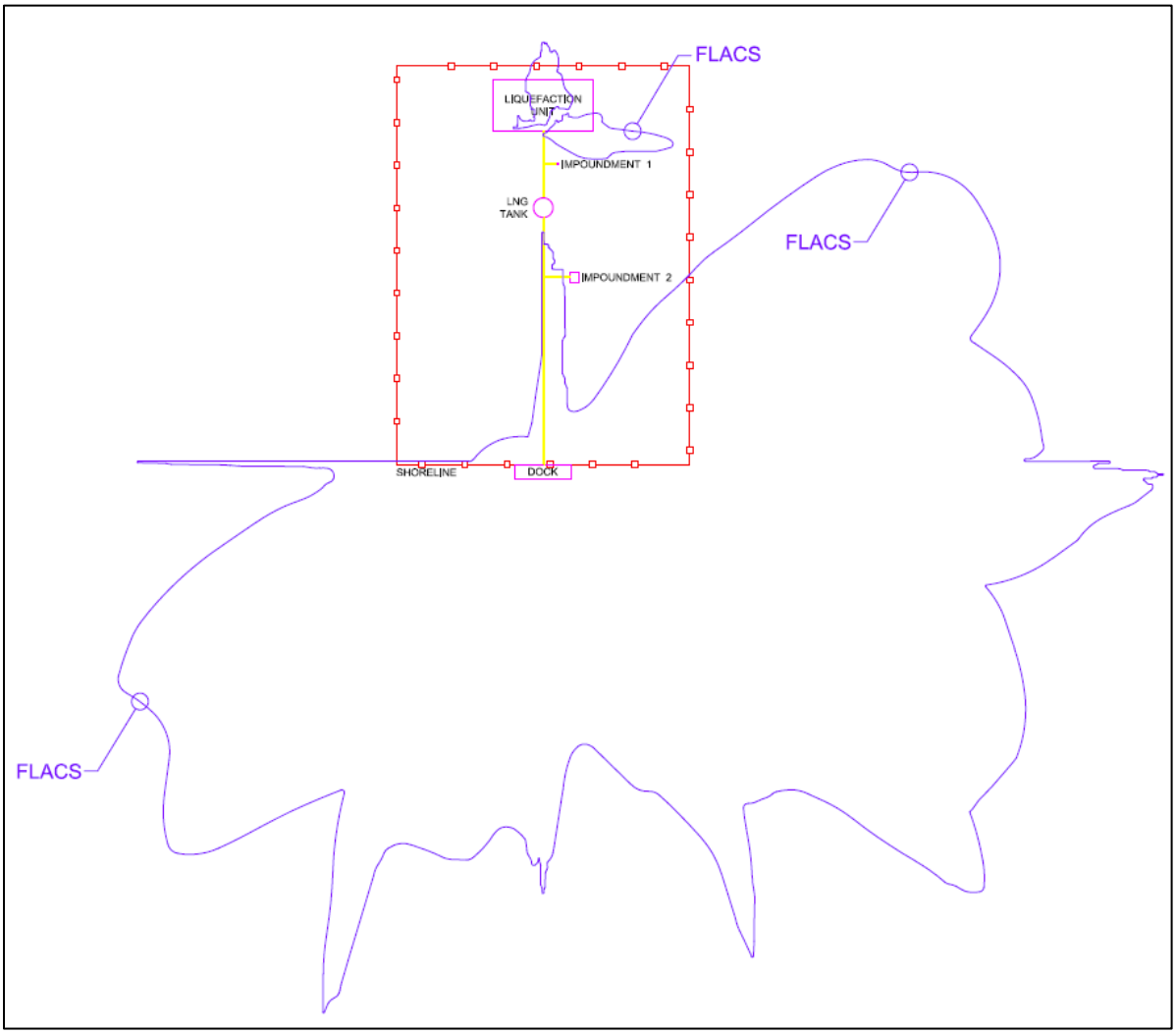

Figure 20.4: Overall Exclusion Zone

21 EXPORT FACILITY VAPOR DISPERSION MODELING

21.1 Jetting and Flashing

The design spills used as the basis for jetting and flashing are detailed in Table 21.1-1.

Table 21.1-1: LNG Single Accidental Leakage Source

Spill Source (Scenario)	Failure Type	Line Size (inch)	Single Accidental Leakage Source (inch)
Rundown Line (E-1)	Pipe	16	Up to 5.3
Rundown Line (E-2)	Connection	4	4

Spill Source (Scenario)	Failure Type	Line Size (inch)	Single Accidental Leakage Source (inch)
Rundown Line (E-3)	Connection	3	3
Rundown Line (E-4)	Connection	2	2
Rundown Line (E-5)	Connection	1	1
Rundown Header (E-6)	Pipe	28	Up to 9.3
Rundown Header (E-7)	Connection	4	4
Rundown Header (E-8)	Connection	3	3
Rundown Header (E-9)	Connection	2	2
Rundown Header (E-10)	Connection	1	1
Marine Loading Line @ Tank (E-11)	Pipe	36	Up to 12
Marine Loading Line @ Tank (E-12)	Connection	4	4
Marine Loading Line @ Tank (E-13)	Connection	3	3
Marine Loading Line @ Tank (E-14)	Connection	2	2
Marine Loading Line @ Tank (E-15)	Connection	1	1
Marine Loading Line @ Jetty (E-16)	Pipe	36	Up to 12
Marine Loading Line @ Jetty (E-17)	Connection	4	4
Marine Loading Line @ Jetty (E-18)	Connection	3	3
Marine Loading Line @ Jetty (E-19)	Connection	2	2
Marine Loading Line @ Jetty (E-20)	Connection	1	1
Truck Loading Line (E-21)	Pipe	4	Up to 4
Truck Loading Line (E-22)	Connection	3	3
Truck Loading Line (E-23)	Connection	2	2
Truck Loading Line (E-24)	Connection	1	1

Operating conditions, such as temperature, pressure, flow rate and release elevation used in the analysis are presented in Table 21.1-2. Pump runout flow conditions associated with depressurization during a release scenario have been considered where applicable.

Table 21.1-2: LNG Process Conditions

Spill Source (Scenario)	Operating Temp (°F)	Operating Pressure (psig)	Operating Mass Flow Rate (lb/hr)	Release Elevation (ft)
Rundown Line (E-1)	-260	50	1,258,346	3
Rundown Line (E-2)	-260	50	1,258,346	3
Rundown Line (E-3)	-260	50	1,258,346	3
Rundown Line (E-4)	-260	50	1,258,346	3

Spill Source (Scenario)	Operating Temp (°F)	Operating Pressure (psig)	Operating Mass Flow Rate (lb/hr)	Release Elevation (ft)
Rundown Line (E-5)	-260	50	1,258,346	3
Rundown Header (E-6)	-260	50	3,775,039	3
Rundown Header (E-7)	-260	50	3,775,039	3
Rundown Header (E-8)	-260	50	3,775,039	3
Rundown Header (E-9)	-260	50	3,775,039	3
Rundown Header (E-10)	-260	50	3,775,039	3
Marine Loading Line @ Tank (E-11)	-260	100	14,222,461	3
Marine Loading Line @ Tank (E-12)	-260	100	14,222,461	3
Marine Loading Line @ Tank (E-13)	-260	100	14,222,461	3
Marine Loading Line @ Tank (E-14)	-260	100	14,222,461	3
Marine Loading Line @ Tank (E-15)	-260	100	14,222,461	3
Marine Loading Line @ Jetty (E-16)	-260	40	14,222,461	30
Marine Loading Line @ Jetty (E-17)	-260	40	14,222,461	30
Marine Loading Line @ Jetty (E-18)	-260	40	14,222,461	30
Marine Loading Line @ Jetty (E-19)	-260	40	14,222,461	30
Marine Loading Line @ Jetty (E-20)	-260	40	14,222,461	30
Truck Loading Line (E-21)	-260	40	80,757	3
Truck Loading Line (E-22)	-260	40	80,757	3
Truck Loading Line (E-23)	-260	40	80,757	3
Truck Loading Line (E-24)	-260	40	80,757	3

In addition to location and flow rate considerations used to determine the design spills to be analyzed for jetting and flashing, the worst-case jetting and flashing scenarios (Bounding Scenarios) for the SALS detailed in Table 21.1-2 will result from a hole size that results in the greatest total vapor mass flow rate. When a pressurized leak occurs, the liquid jet will atomize and, depending on the operating conditions and release elevation, a portion of the jet may rainout and pool on the ground. Since the greatest total vapor mass flow rate associated with a single accidental leakage source may not occur at the largest hole size, PHAST was used to perform a sensitivity analysis on multiple hole sizes for pipe failures.

Table 21.1-3 presents the results of a sensitivity study for the scenarios to determine the Bounding Scenarios for pipe failures.

Table 21.1-3: Jetting and Flashing Sensitivity Study

Spill Source (Scenario)	Hole Size (in)	Equilibrium Pressure (psig)	Rainout %	Release Vapor Mass Flow Rate (lb/hr)	Pool Vapor Mass Flow Rate (lb/hr)	Total Vapor Mass Flow Rate (lb/hr)
Rundown Line (E-1)	5.3	50	46	627,600	452,000	1,080,000
Rundown Header (E-6)	9.3	50	66	1,206,000	1,987,000	3,193,000
Marine Loading Line @ Tank (E-11)	12	100	56	3,176,000	3,925,000	7,642,000
Marine Loading Line @ Jetty (E-16)	12	40	59	2,158,000	2,649,000	4,808,000
Truck Loading Line (E-21)	1.48	40	0	80,913	0	90,813

Based on the sensitivity study detailed in Table 21.1-3 and the design spills determined for all hole sizes, Table 21.1-4 presents the worst-case scenarios to be modeled.

Table 21.1-4: Worst Case Scenarios

Spill Scenario	Location/Spill Source:	Hole Size (in)
E-1	Rundown Line	5.3
E-6	Rundown Header	9.3
E-11	Marine Loading Line at Storage Tank	12
E-16	Marine Loading Line at Jetty	12
E-21	Truck Loading Line	1.48

Figure 21.1-1 illustrates the release location for the worst-case scenarios described in Table 21.1-4:

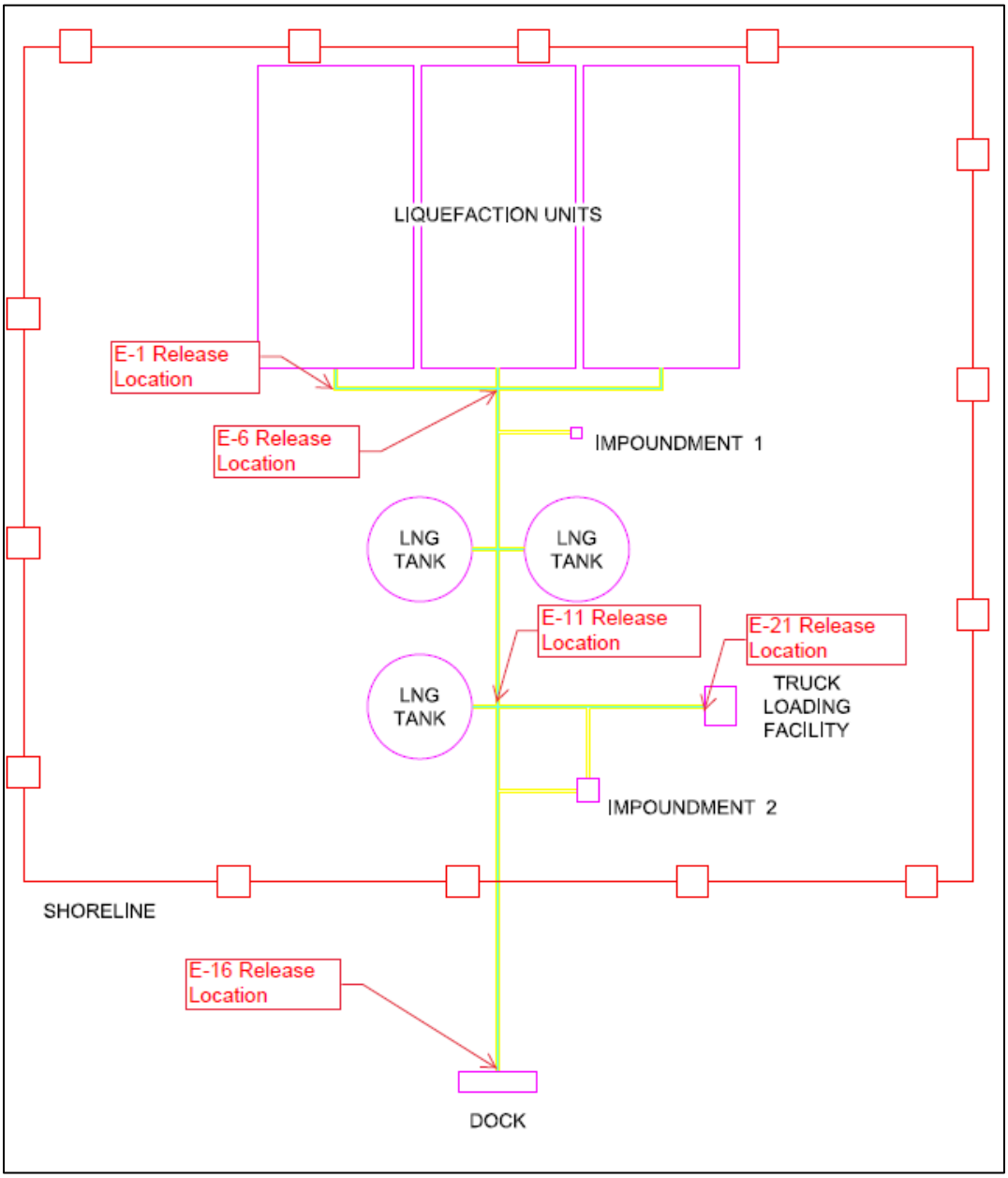

Figure 21.1-1: Jetting and Flashing Release Locations

The results of the modeling are included in Table 21.1-5.

Table 21.1-5 LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast Distance to ½ LFL (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)	FLACS Distance to ½ LFL (With Geometry) (ft)
E-1	2	0.03	2,421.65	3,854.99	Varies with direction
E-1	1	0.03	3,135.46	4,658.79	Varies with direction
E-1	2	0.01	3,178.75	N/A	Varies with direction
E-1	1	0.01	3,116.84	N/A	Varies with direction
E-6	2	0.03	3,732.36	6,266.40	Varies with direction
E-6	1	0.03	4,915.87	6,660.11	Varies with direction
E-6	2	0.01	5,106.40	N/A	Varies with direction
E-6	1	0.01	5,656.72	N/A	Varies with direction
E-11	2	0.03	7,259.66	9,842.52	Varies with direction
E-11	1	0.03	6,719.98	6,971.79	Varies with direction
E-11	2	0.01	8,491.48	N/A	Varies with direction
E-11	1	0.01	5,361.25	N/A	Varies with direction
E-16	2	0.03	5,146.81	6,561.68	Varies with direction
E-16	1	0.03	6,793.74	8,202.1	Varies with direction
E-16	2	0.01	6,719.94	N/A	Varies with direction
E-16	1	0.01	5,507.93	N/A	Varies with direction
E-21	2	0.03	705.59	1099.08	Varies with direction
E-21	1	0.03	895.76	1328.74	Varies with direction
E-21	2	0.01	860.70	N/A	Varies with direction

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast Distance to ½ LFL (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)	FLACS Distance to ½ LFL (With Geometry) (ft)
E-21	1	0.01	1,115.50	N/A	Varies with direction

The results of the jetting and flashing vapor dispersion modeling are illustrated in the following figures:

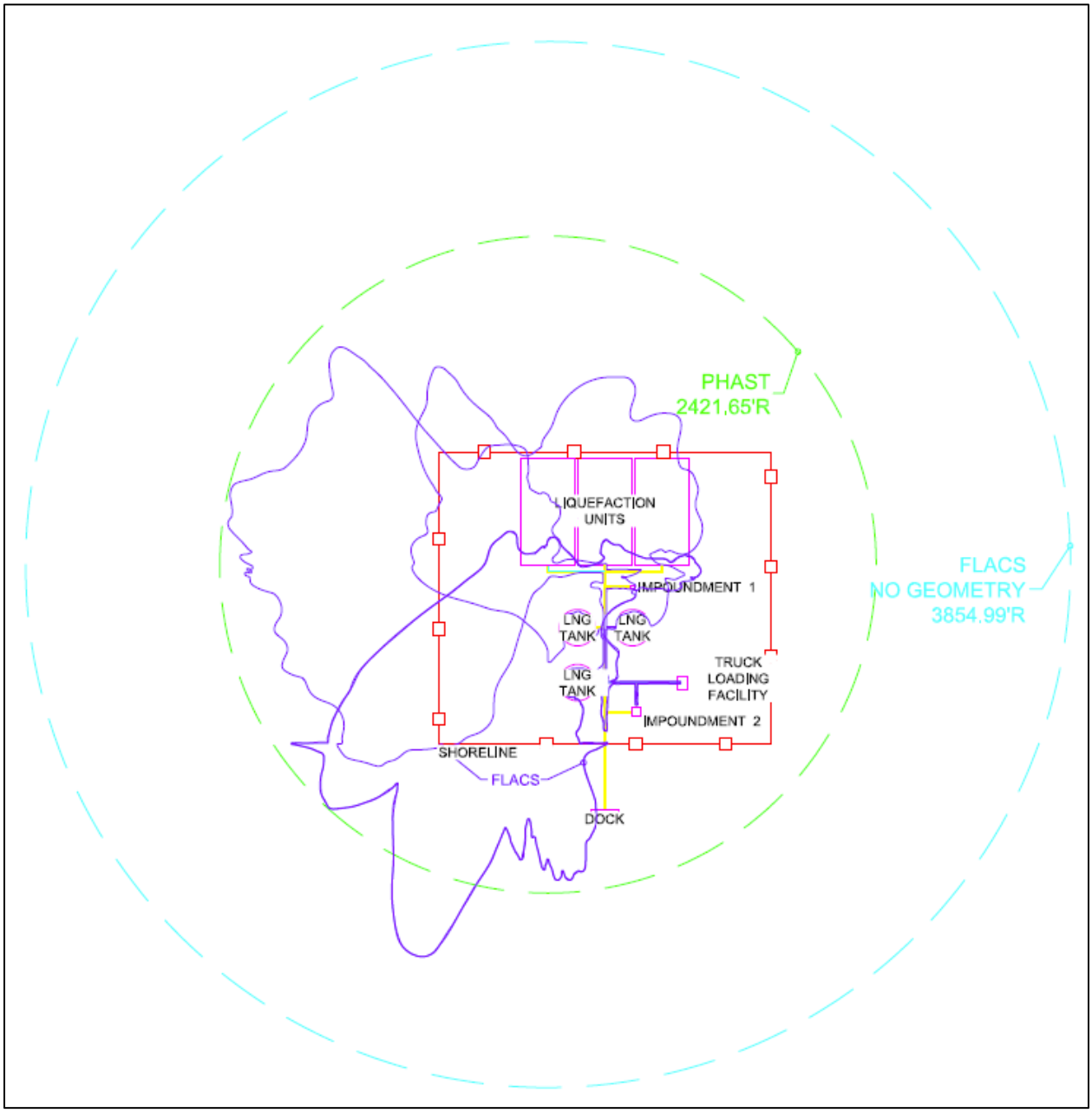

Figure 21.1-2: Rundown Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-2 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

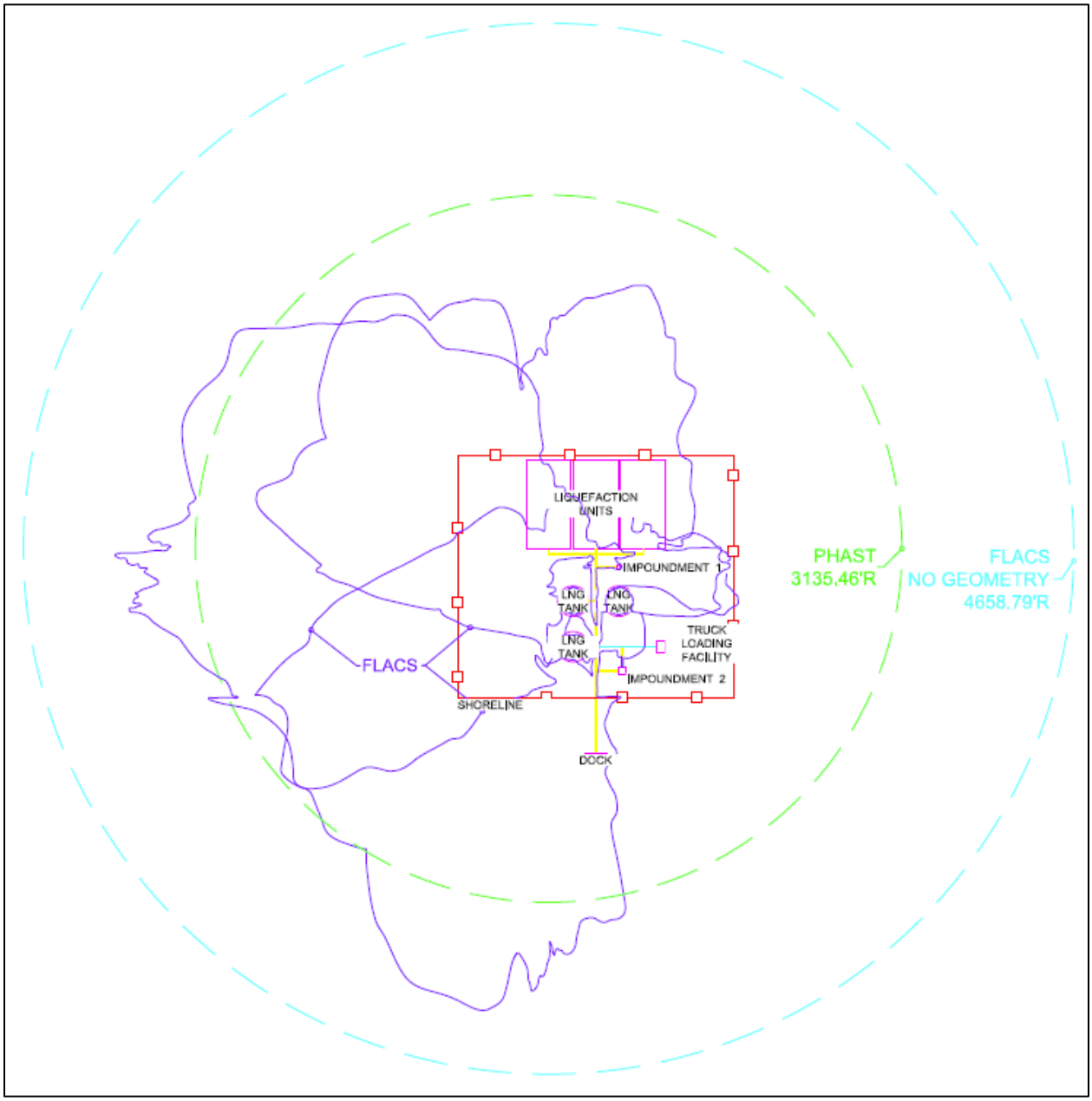

Figure 21.1-3: Rundown Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-3 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

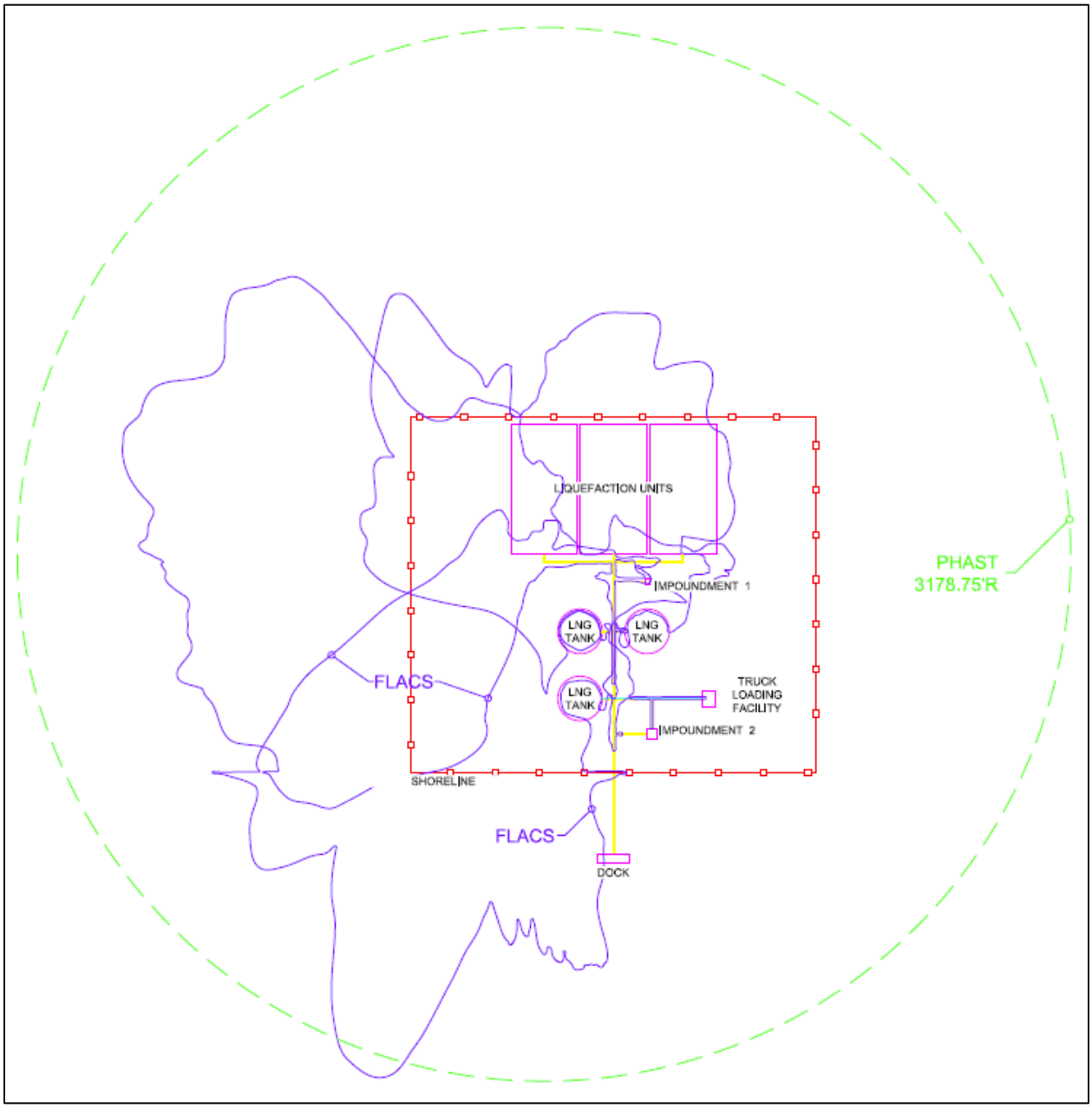

Figure 21.1-4: Rundown Line (2 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-4 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

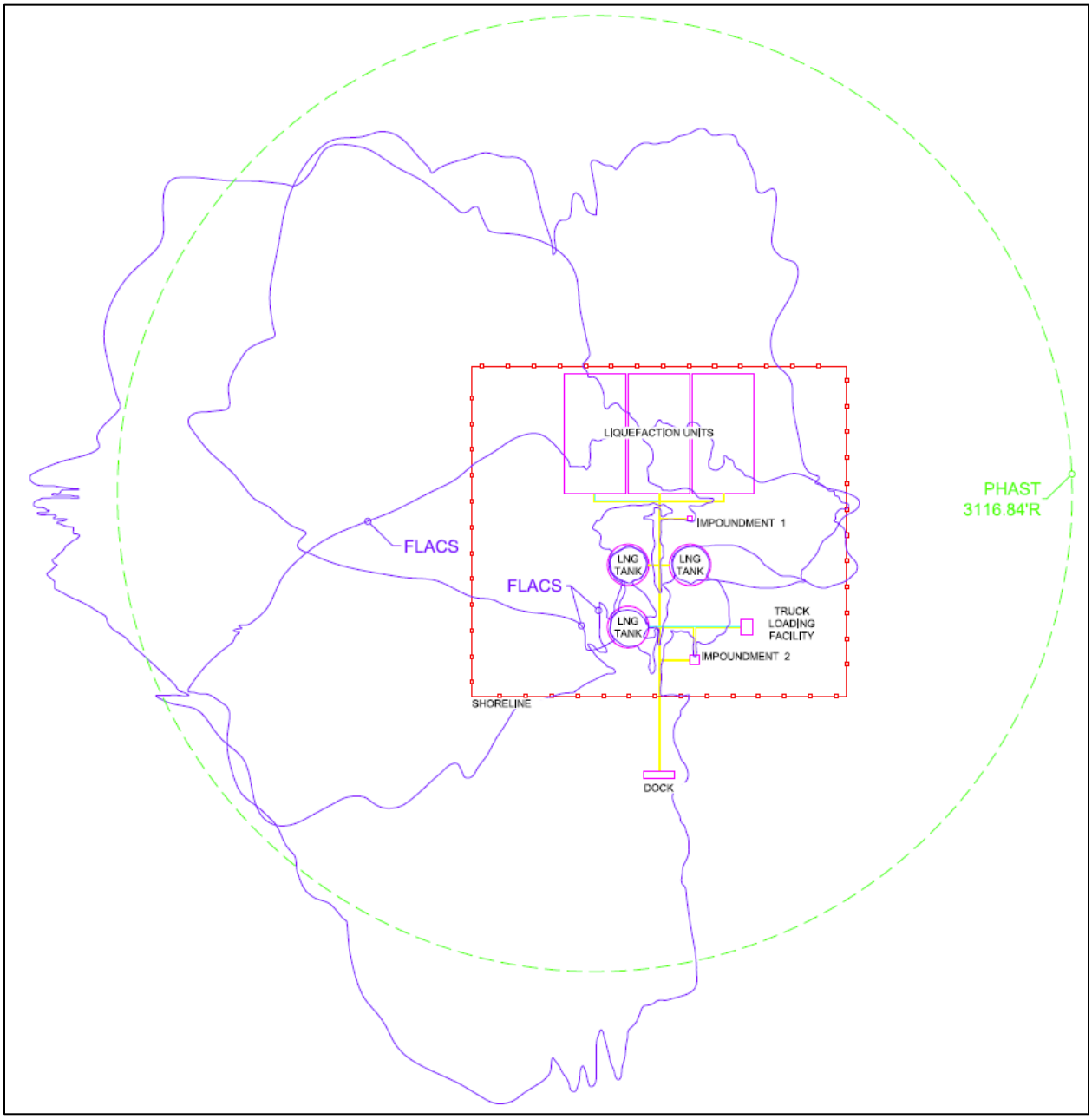

Figure 21.1-5: Rundown Line (1 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-5 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

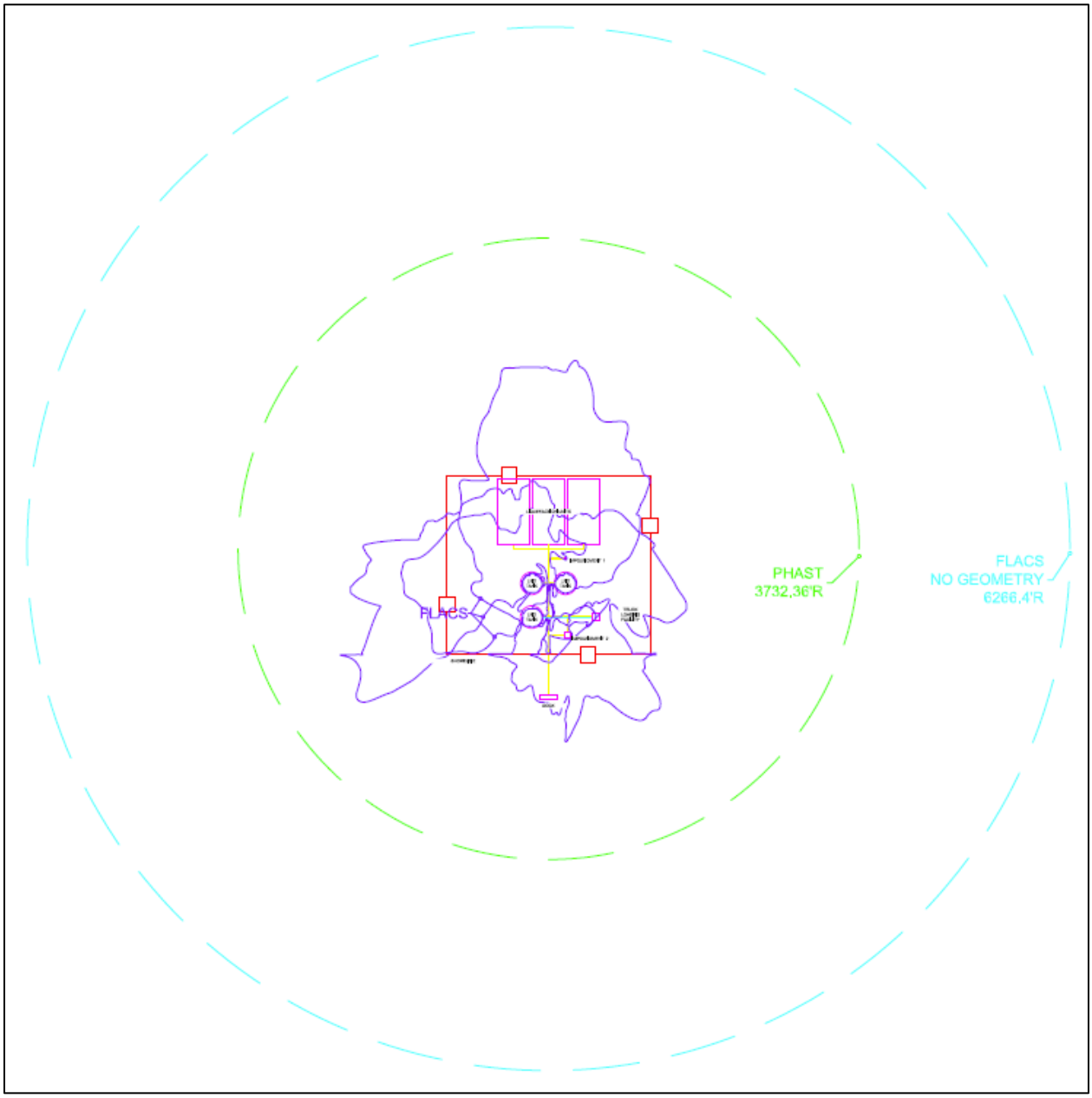

Figure 21.1-6: Rundown Header (2 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-6 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

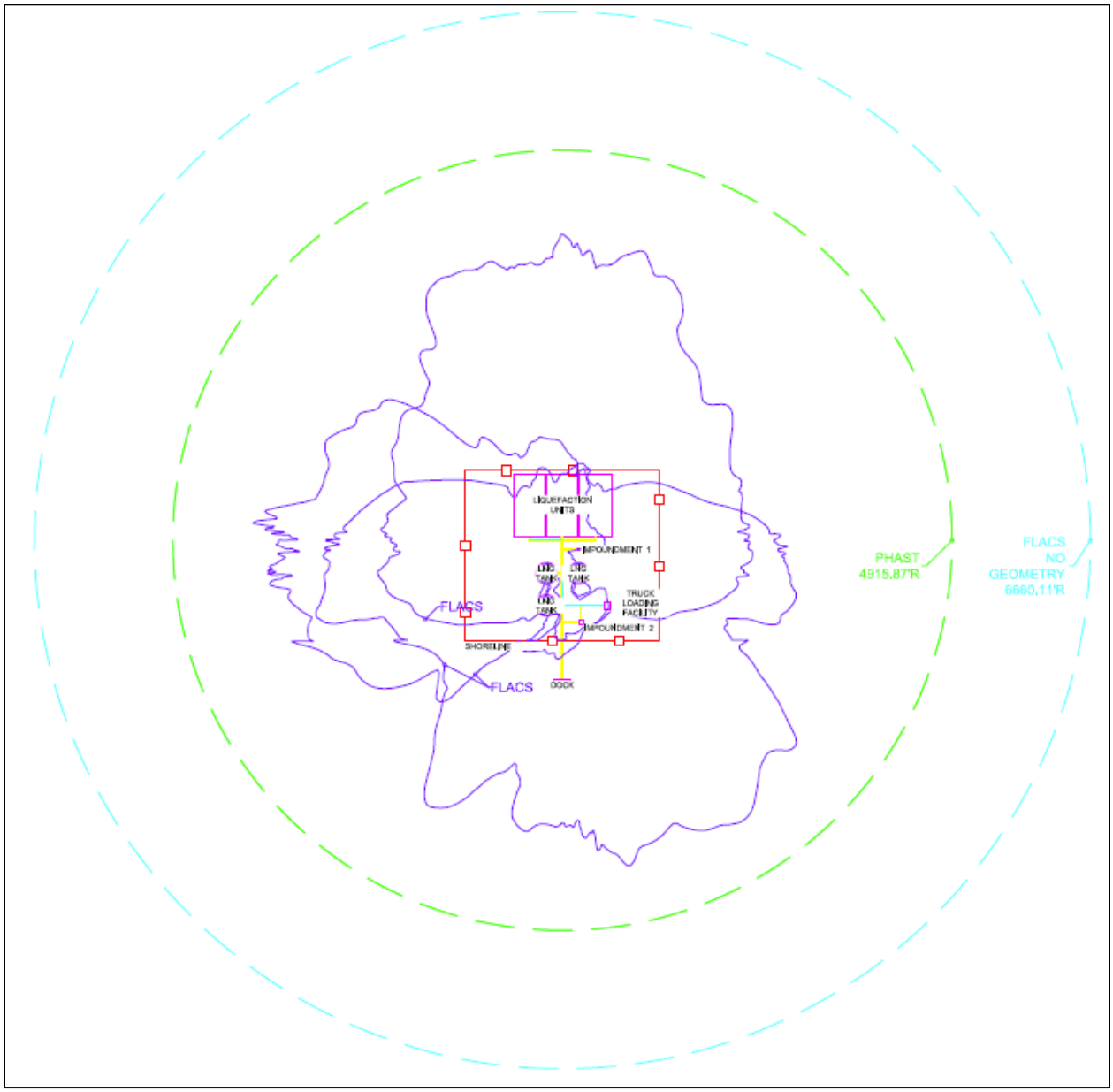

Figure 21.1-7: Rundown Header (1 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-7 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

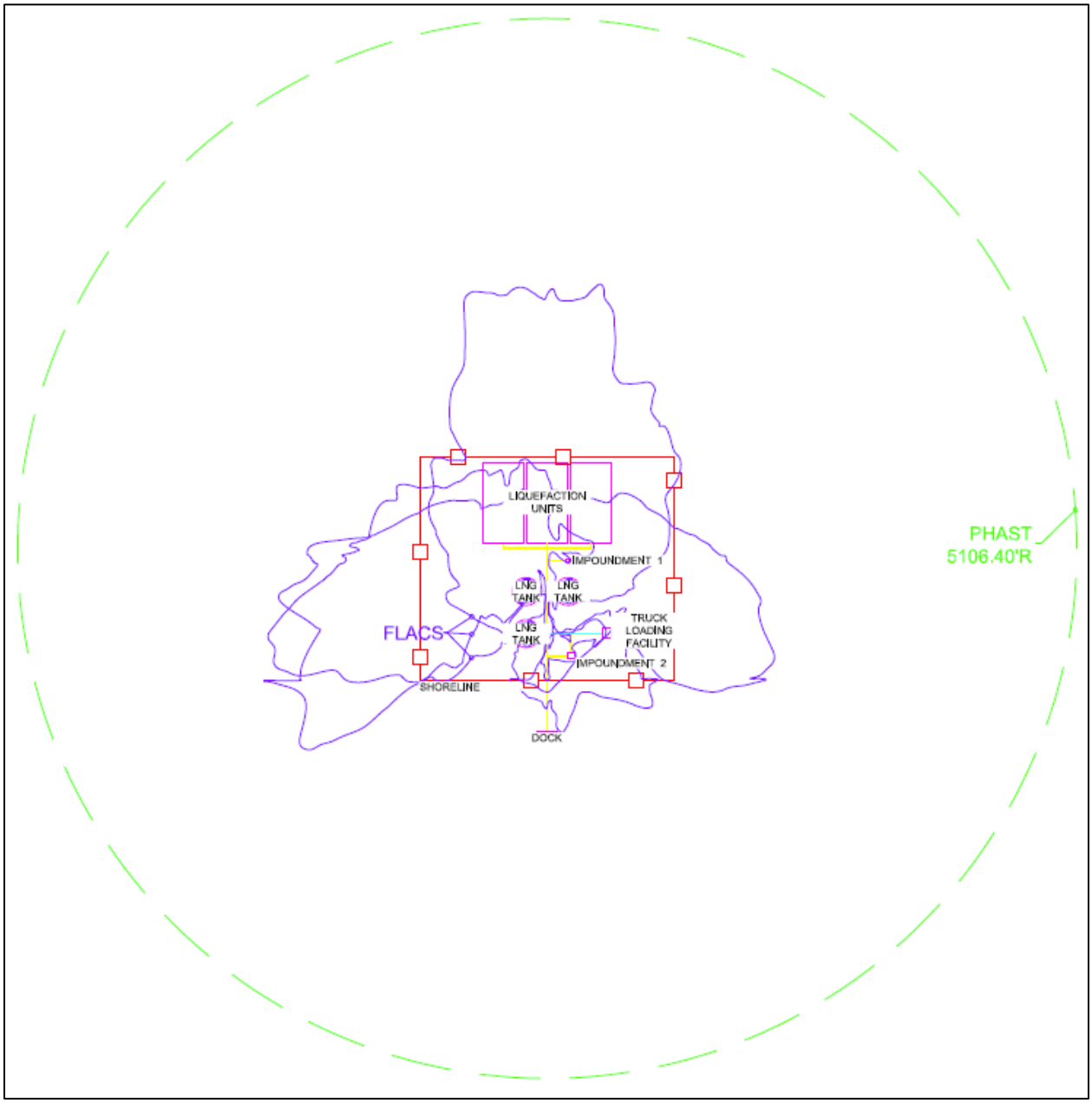

Figure 21.1-8: Rundown Header (2 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-8 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

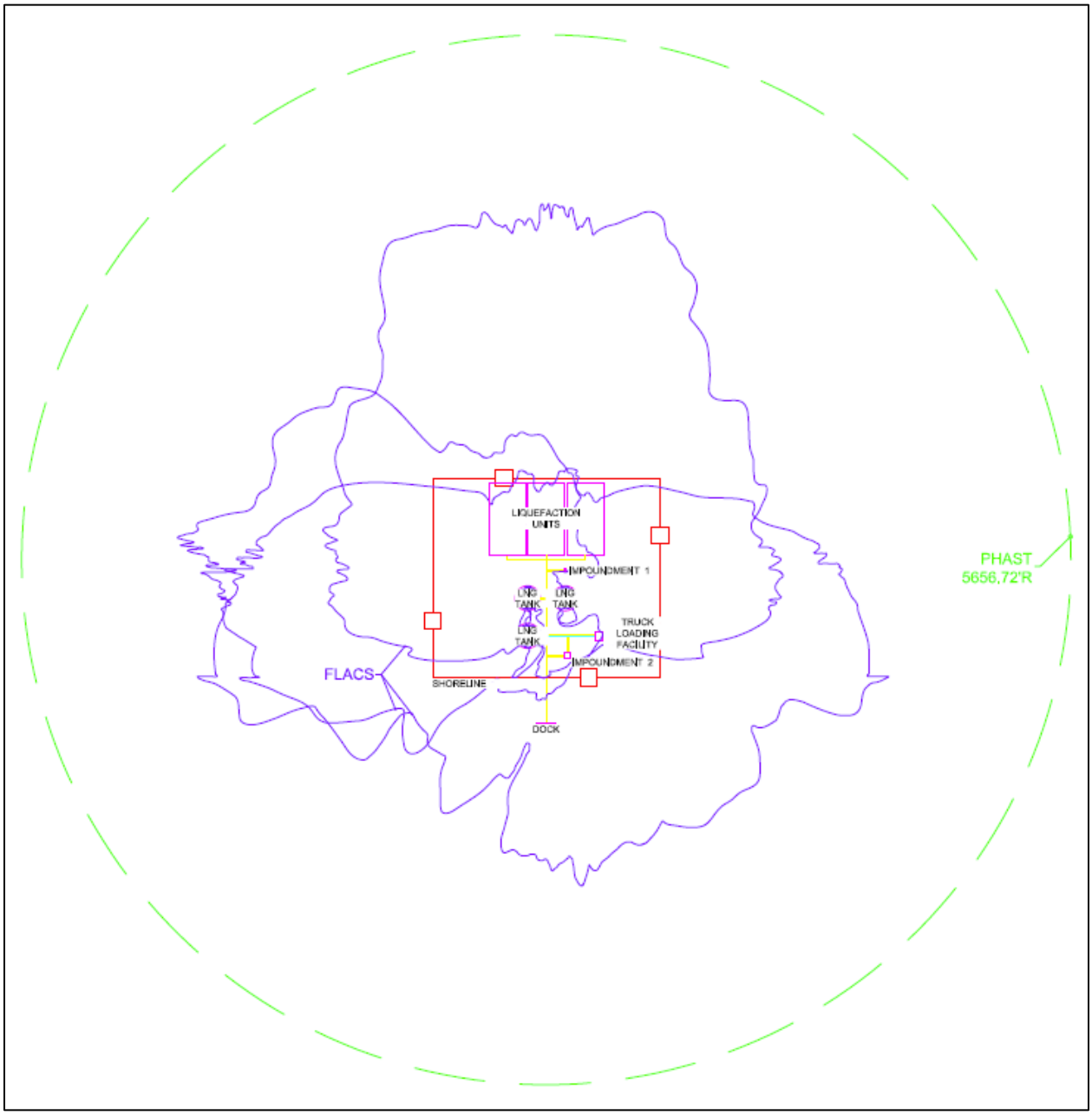

Figure 21.1-9: Rundown Header (1 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-9 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

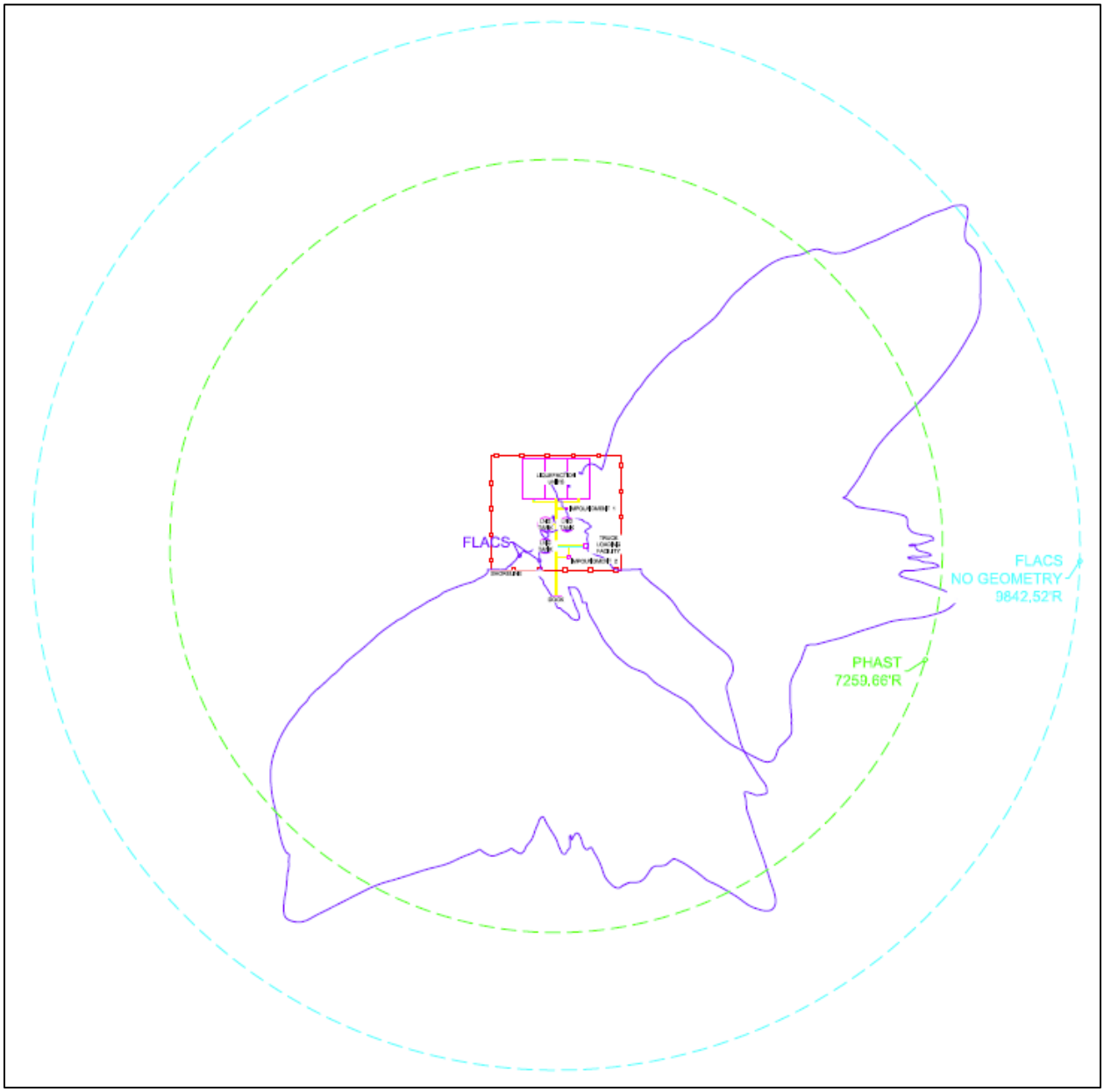

Figure 21.1-10: Marine Loading Line at Storage Tank (2 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-10 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

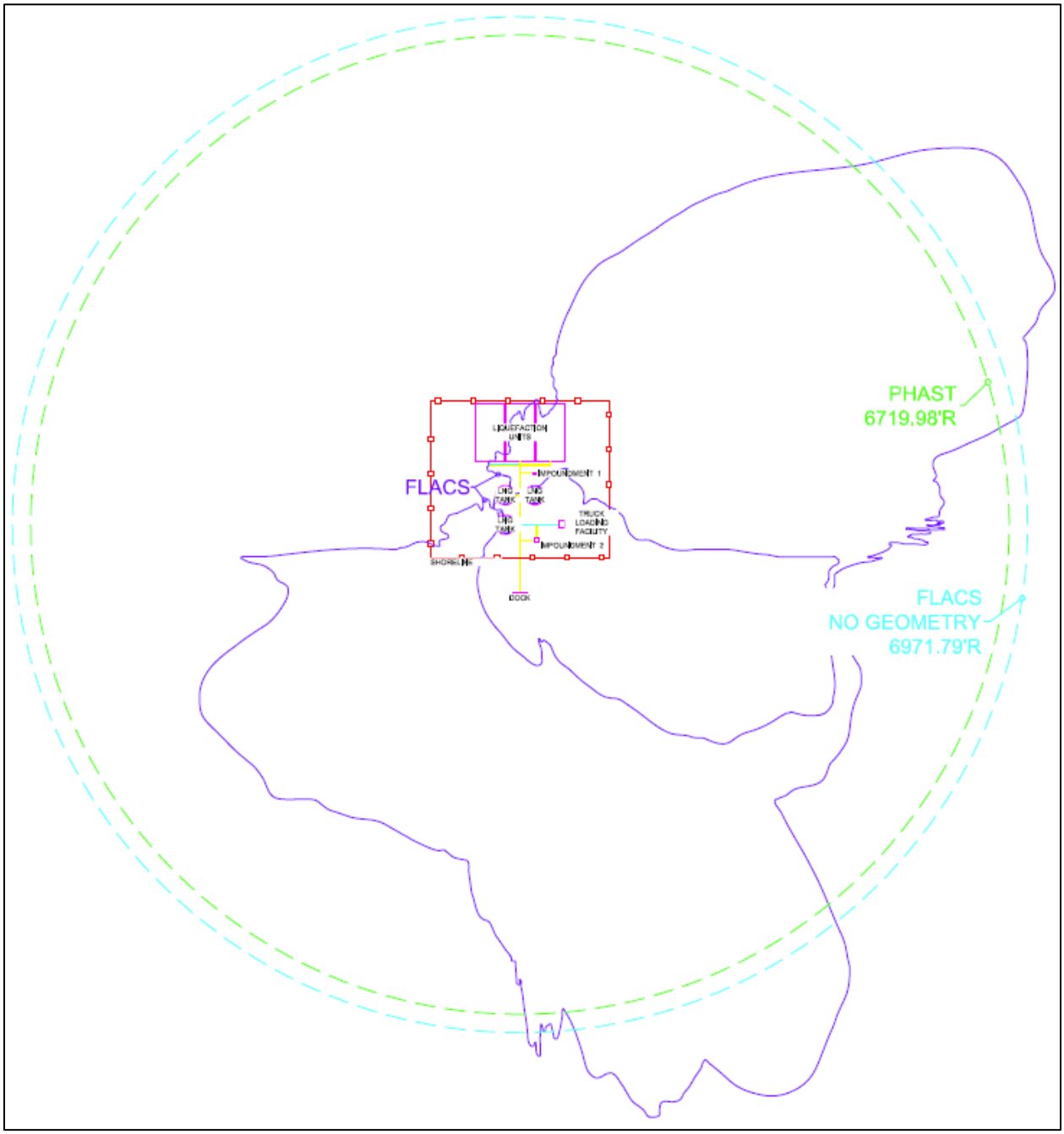

Figure 21.1-11: Marine Loading Line at Storage Tank (1 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-11 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

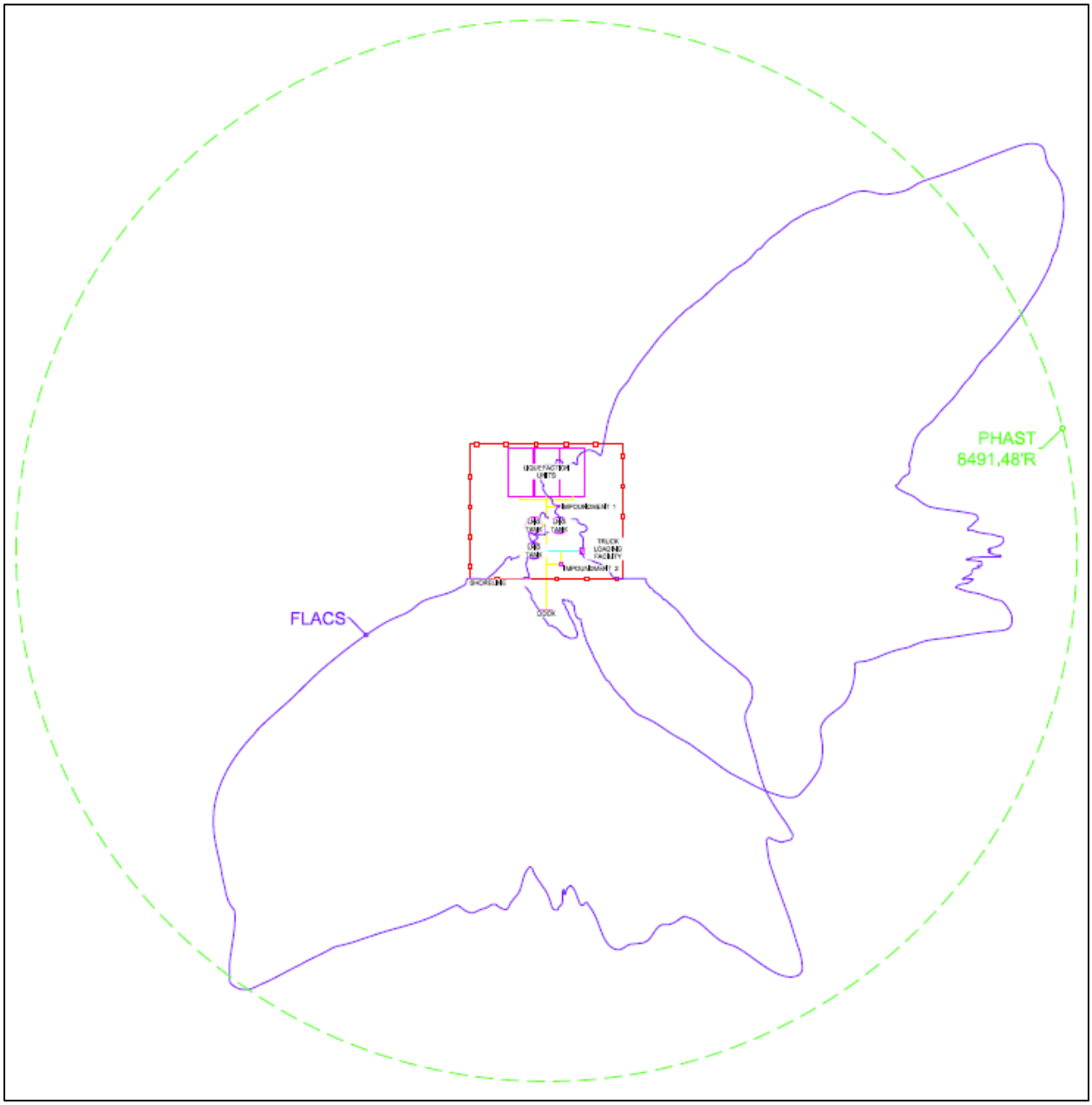

Figure 21.1-12: Marine Loading Line at Storage Tank (2 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-12 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

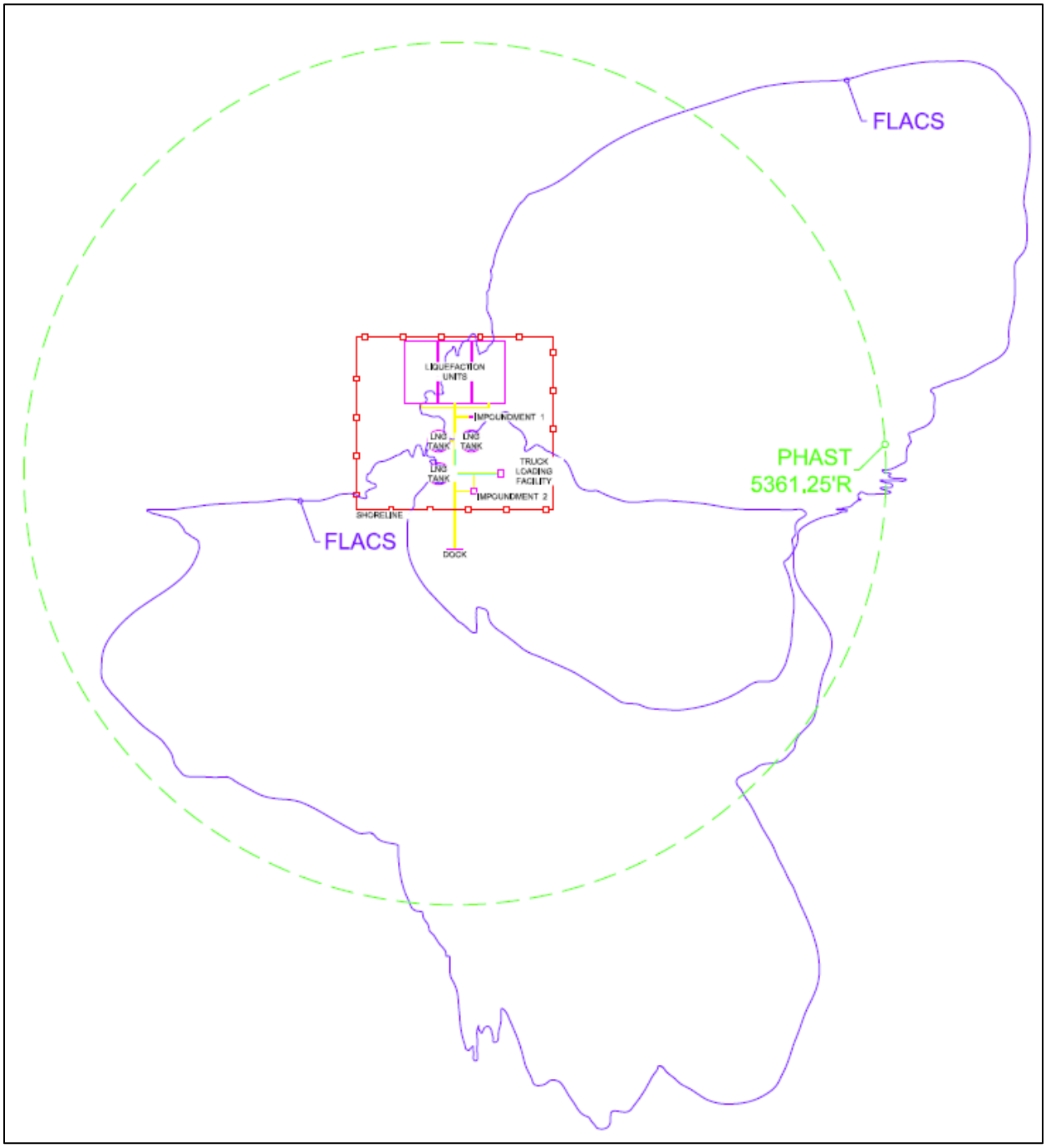

Figure 21.1-13: Marine Loading Line at Storage Tank (1 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-13 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

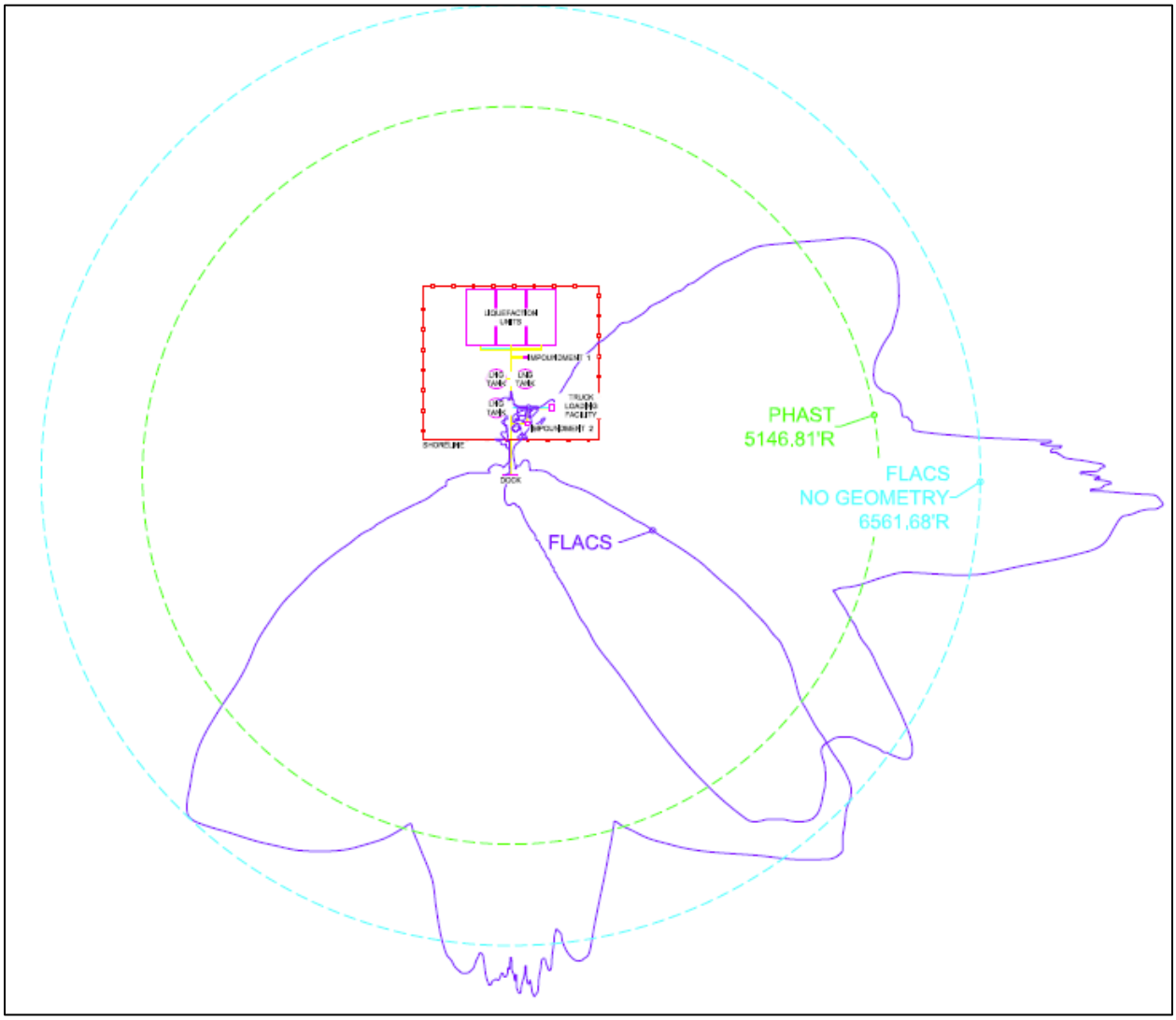

Figure 21.1-14: Marine Loading Line at Jetty (2 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-14 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

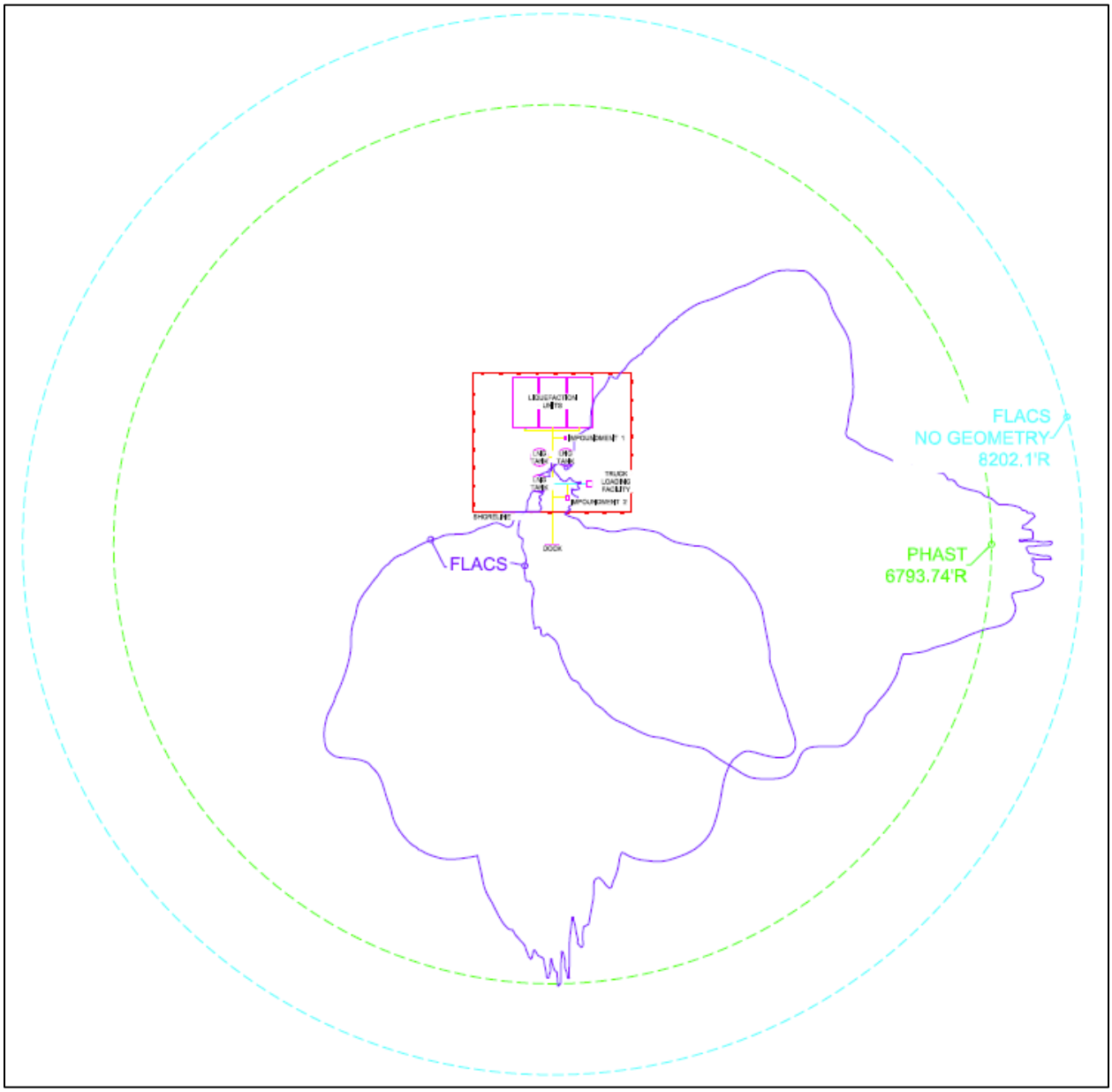

Figure 21.1-15: Marine Loading Line at Jetty (1 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-15 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

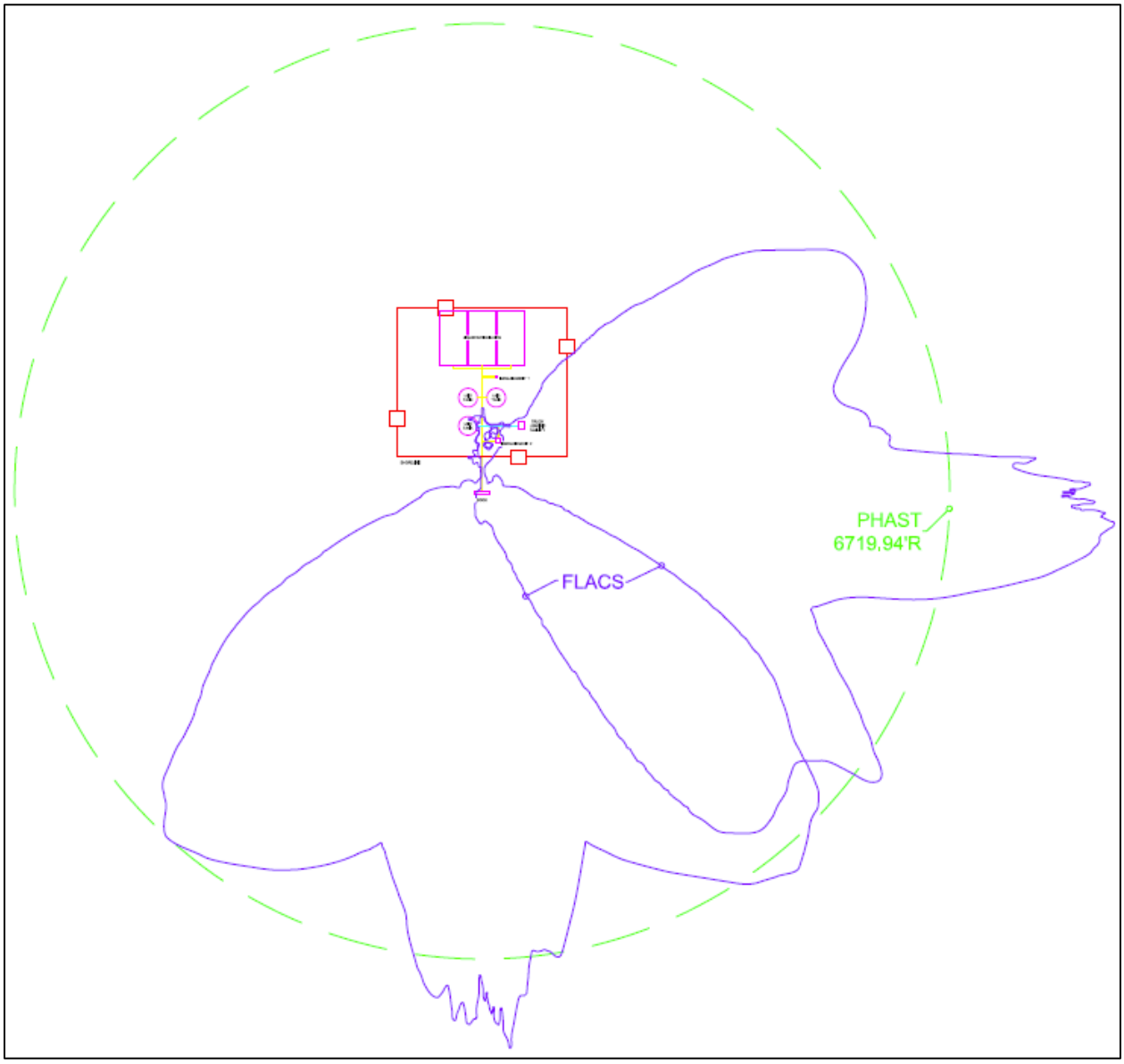

Figure 21.1-16: Marine Loading Line at Jetty (2 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-16 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

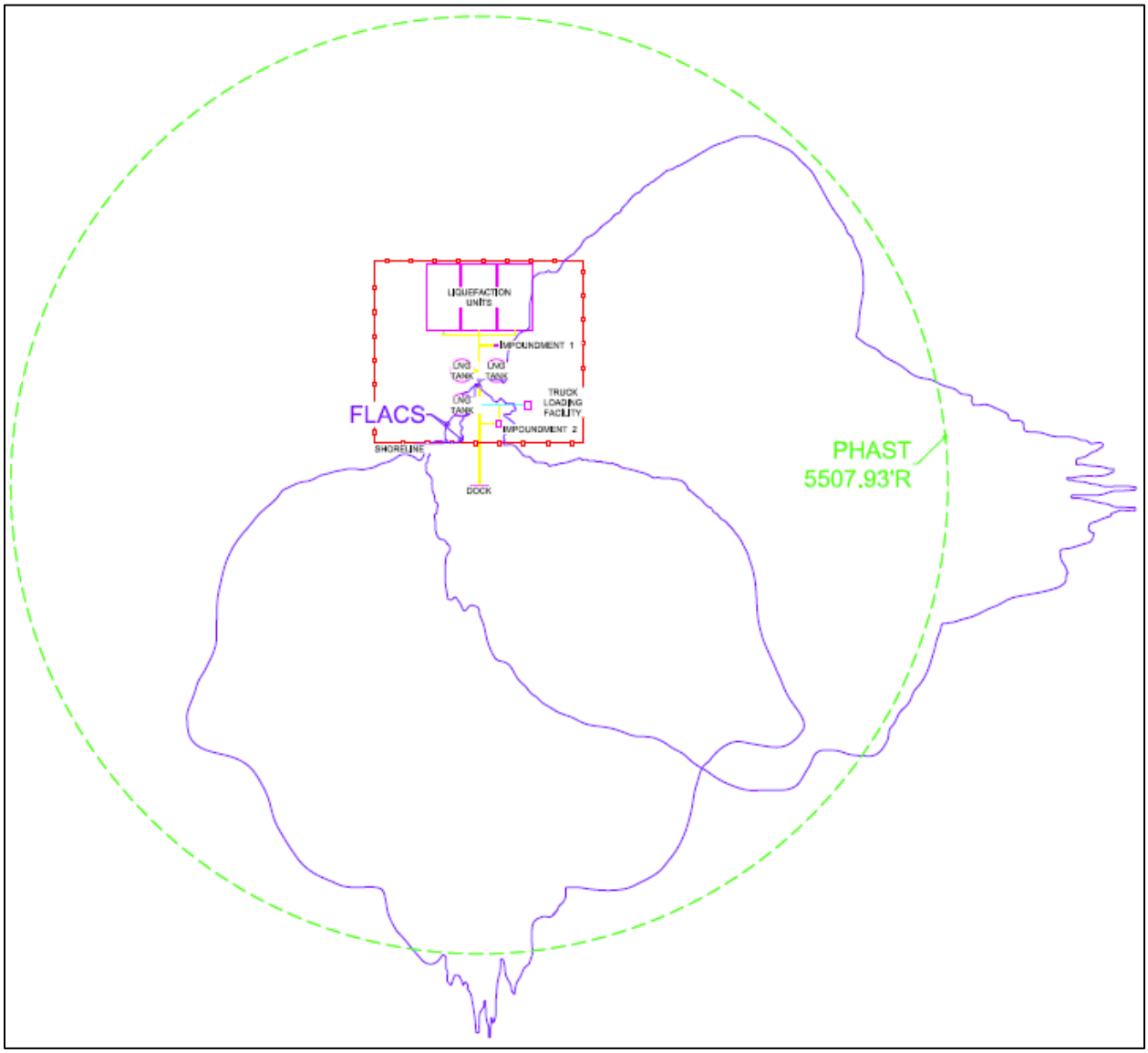

Figure 21.1-17: Marine Loading Line at Jetty (1 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-17 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

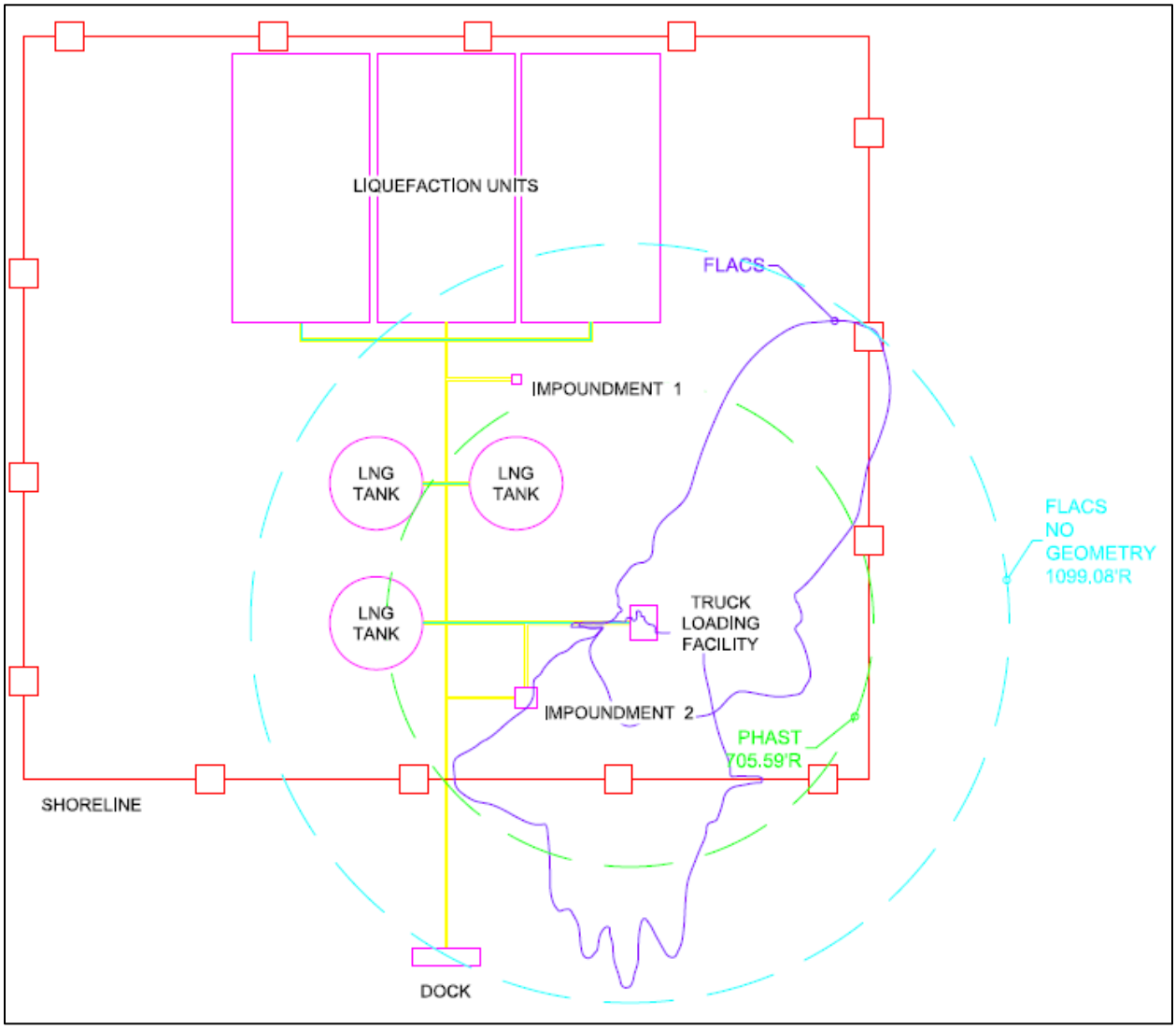

Figure 21.1-18: Truck Loading Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-18 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

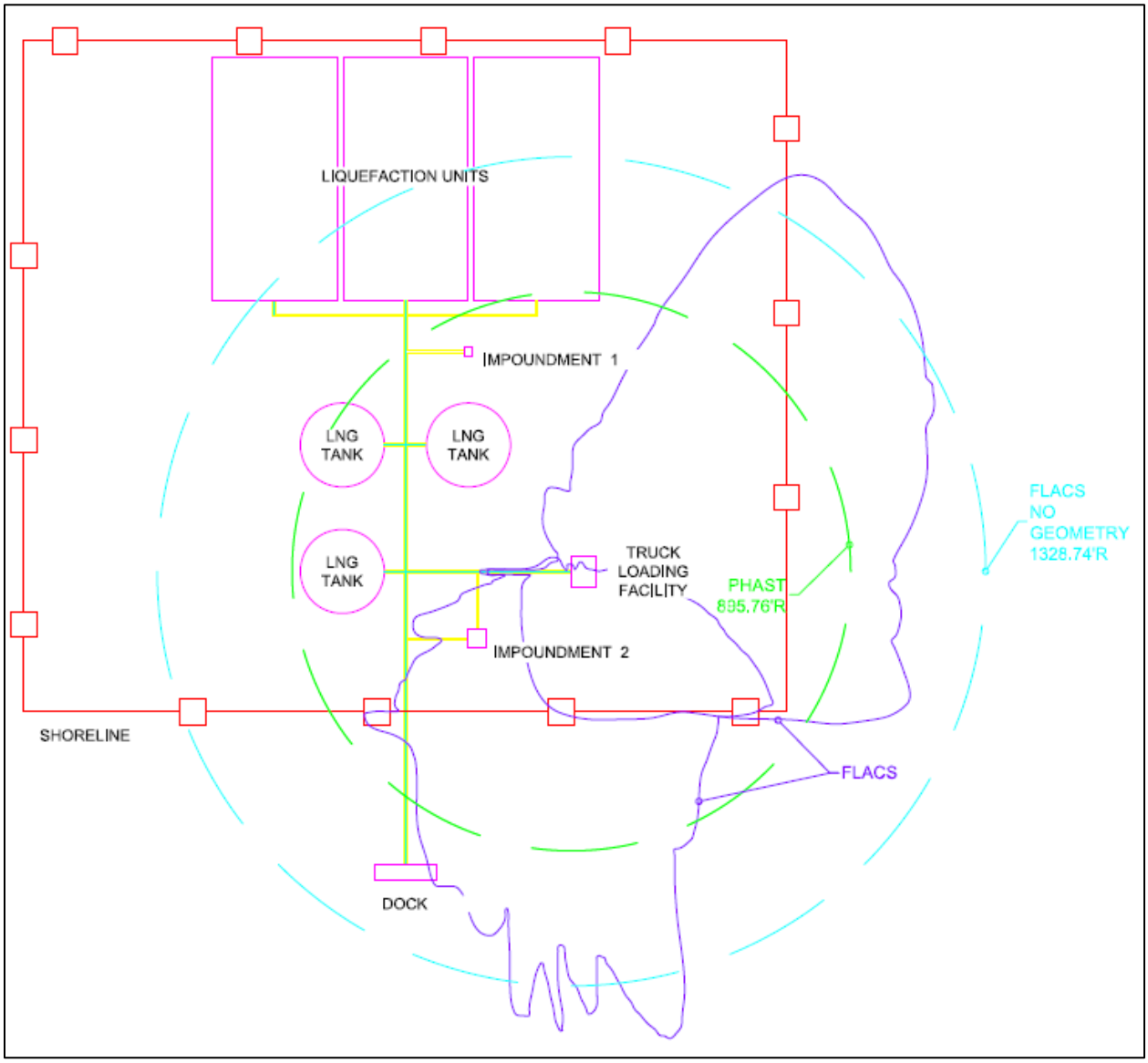

Figure 21.1-19: Truck Loading Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 21.1-19 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

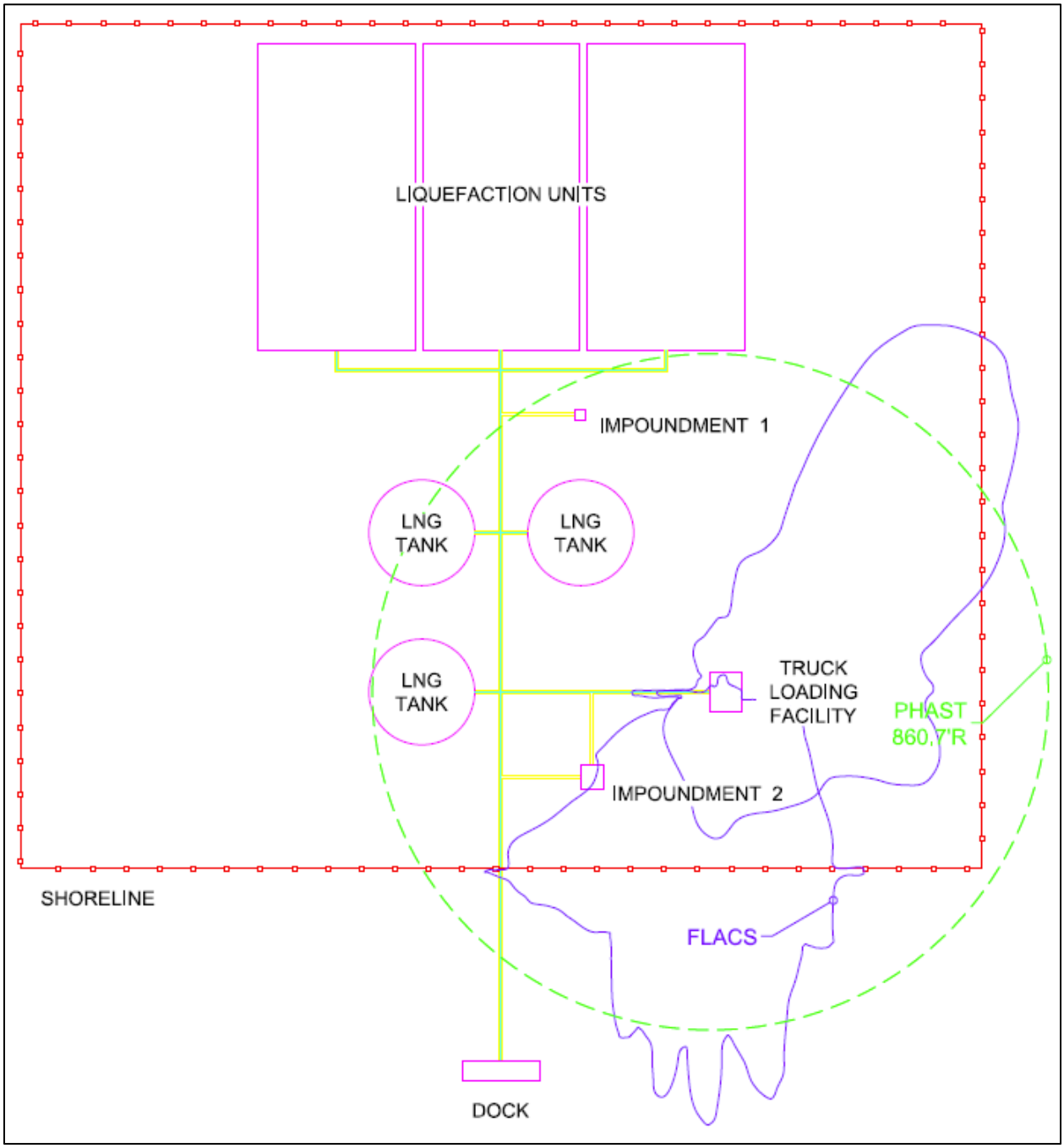

Figure 21.1-20: Truck Loading Line (2 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-20 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

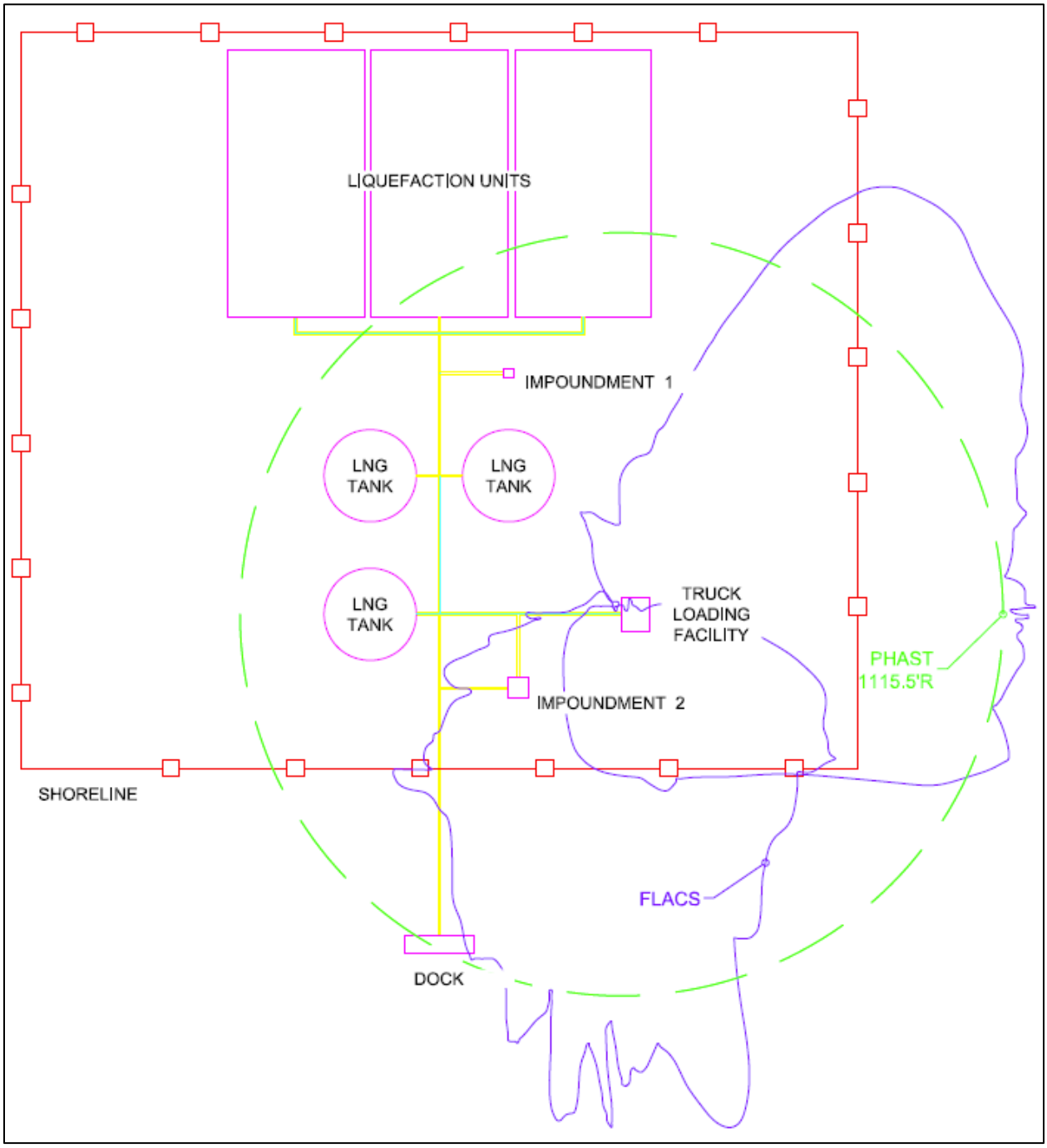

Figure 21.1-21: Truck Loading Line (1 m/s, 0.01m)

The FLACS results illustrated in Figure 21.1-21 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (2) a release direction to the South with winds blowing to the South, Southwest, and Southeast.

Results Discussion:

For the rundown line, the results are generally comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 2 between the Phast and FLACS models. All models extend significantly beyond the property line due to the very large hole size required to be modeled for this release.

For the rundown header, the results are generally comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 2 between the Phast and FLACS models. All models extend significantly beyond the property line due to the very large hole size required to be modeled for this release.

For the marine transfer line, the results are generally comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results range from very close to within a factor of 2 between the Phast and FLACS models. All models extend significantly beyond the property line due to the very large hole size required to be modeled for this release.

For the truck loading line, the results are generally comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 2 between the Phast and FLACS models.

21.2 LNG Conveyance

The design spills used as the basis for conveyance to impoundments are detailed in Table 21.2.

Table 21.2: LNG Conveyance Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10-Minute Spill Volume (ft^3)	Spill Containment Dimensions (ft x ft)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)
Rundown Line (E-1)	1,207,443	7,187	4 x 4	28 x 28 x 29	22,736
Rundown Header (E-6)	3,697,796	22,011	4 x 4	28 x 28 x 29	22,736
Marine Loading Line at Storage Tank (E-11)	8,644,638	51,456	4 x 4	60 x 60 x 20	72,000

Spill Source (Scenario)	Flow Rate (lb/hr)	10-Minute Spill Volume (ft^3)	Spill Containment Dimensions (ft x ft)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)
Marine Loading Line at Storage Jetty (E-16)	5,467,349	32,544	4 x 4	60 x 60 x 20	72,000
Truck Loading Line (E-21)	80,757	481	4 x 4	60 x 60 x 20	72,000

Figure 21.2-1 illustrates the release location for the worst-case scenarios described in Table 21.2:

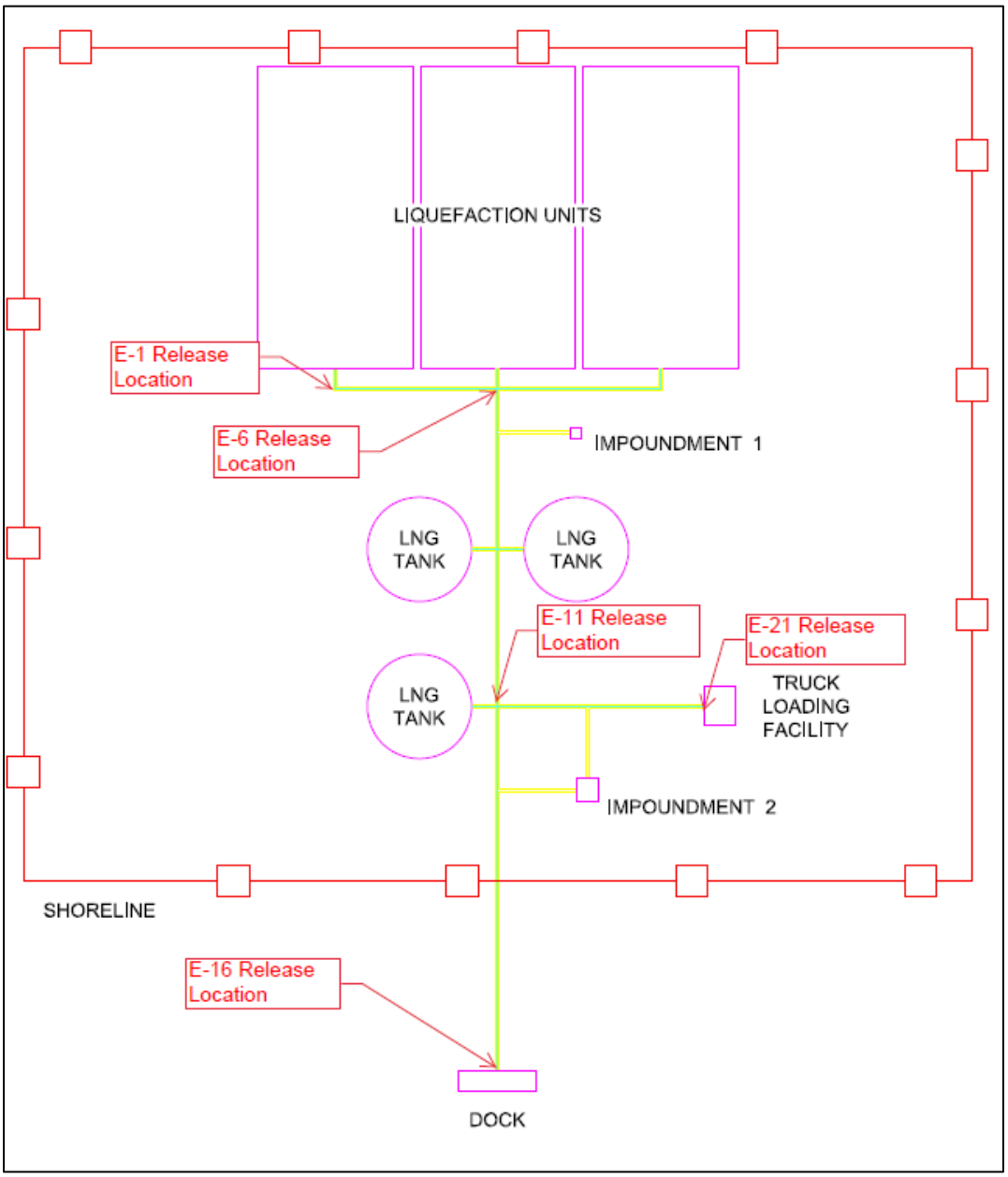

Figure 21.2-1: Conveyance Release Locations

All FLACS releases for LNG conveyance are for a release from the spill location as shown in Figure 21.2-1 into the spill containment system flowing towards the impoundment. The spill direction into the spill containment system is towards the impoundment. The results are presented in combined figures for winds blowing in the North, South, East, and West directions.

The results of the LNG conveyance to impoundment vapor dispersion modeling are illustrated in the following figures:

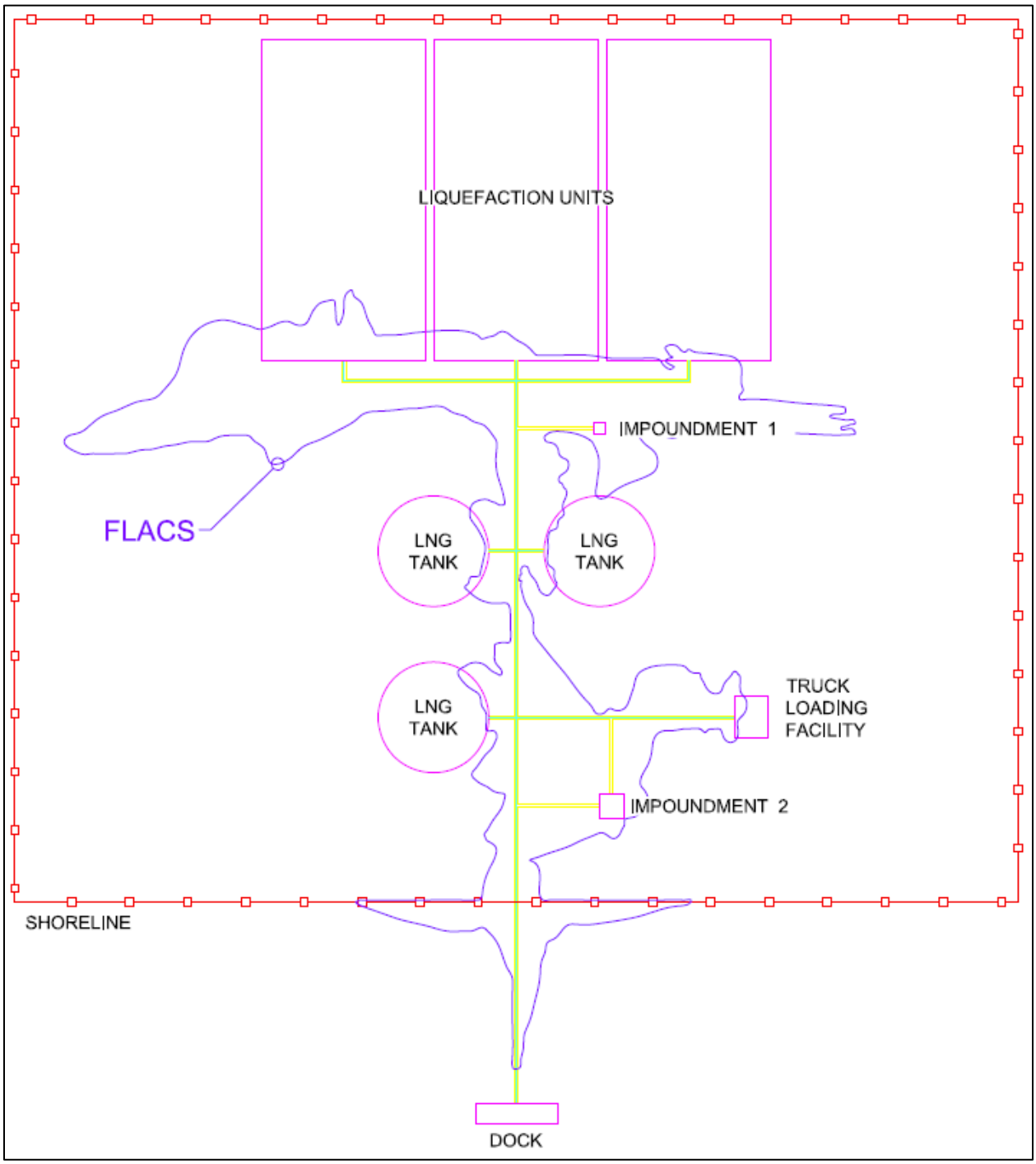

Figure 21.2-2: Rundown Line (2 m/s, 0.03m)

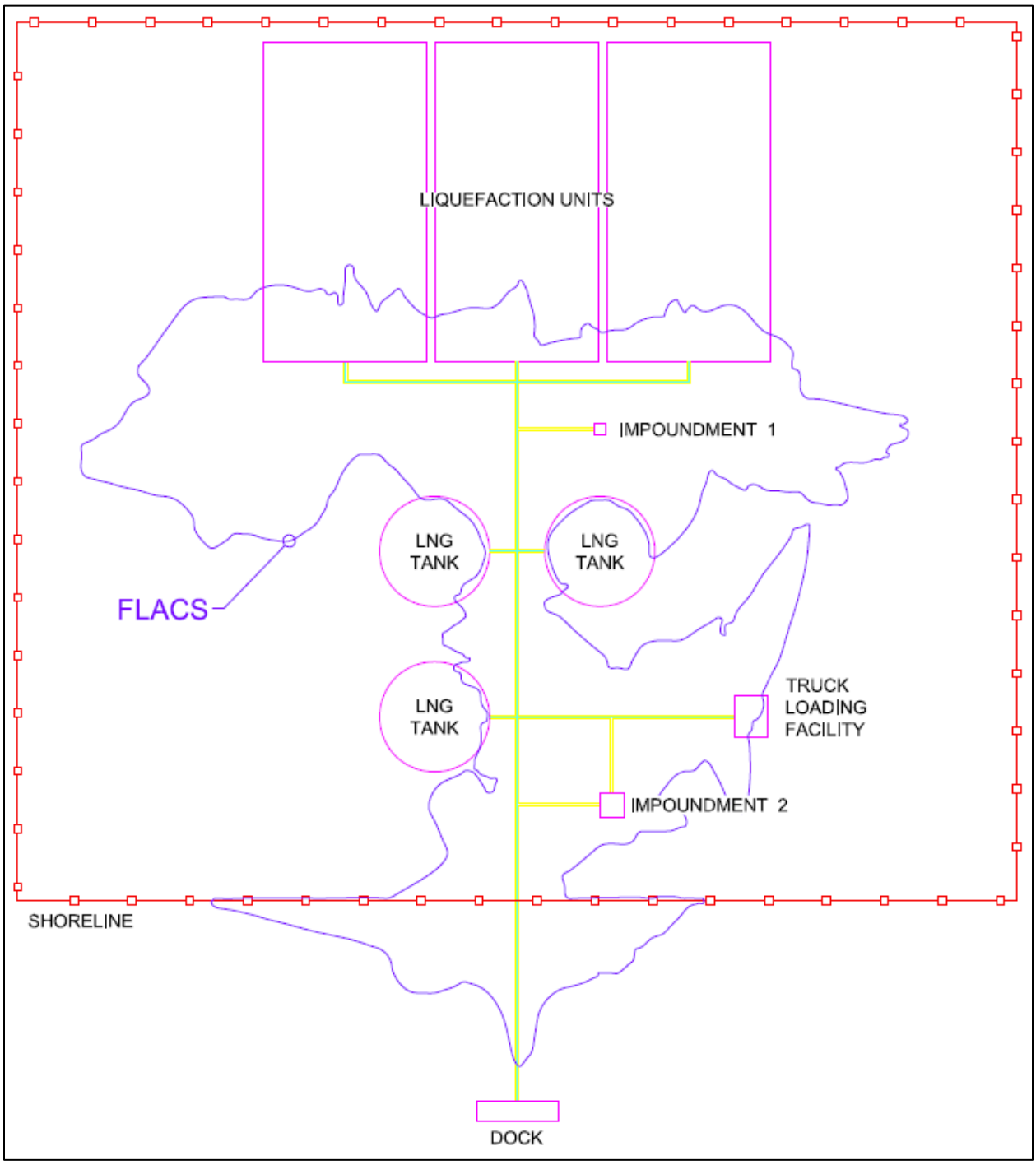

Figure 21.2-3: Rundown Line (1 m/s, 0.03m)

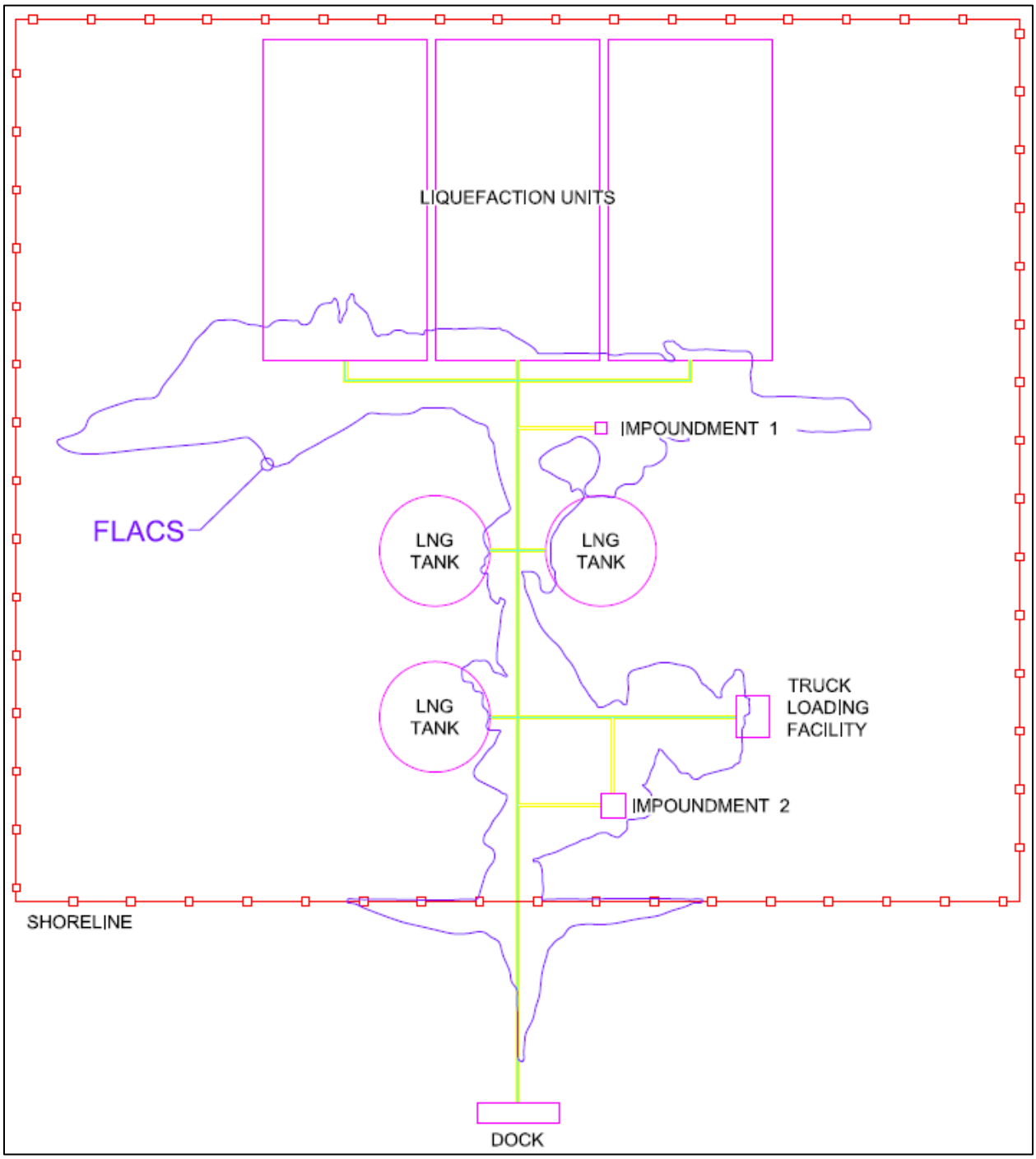

Figure 21.2-4: Rundown Line (2 m/s, 0.01m)

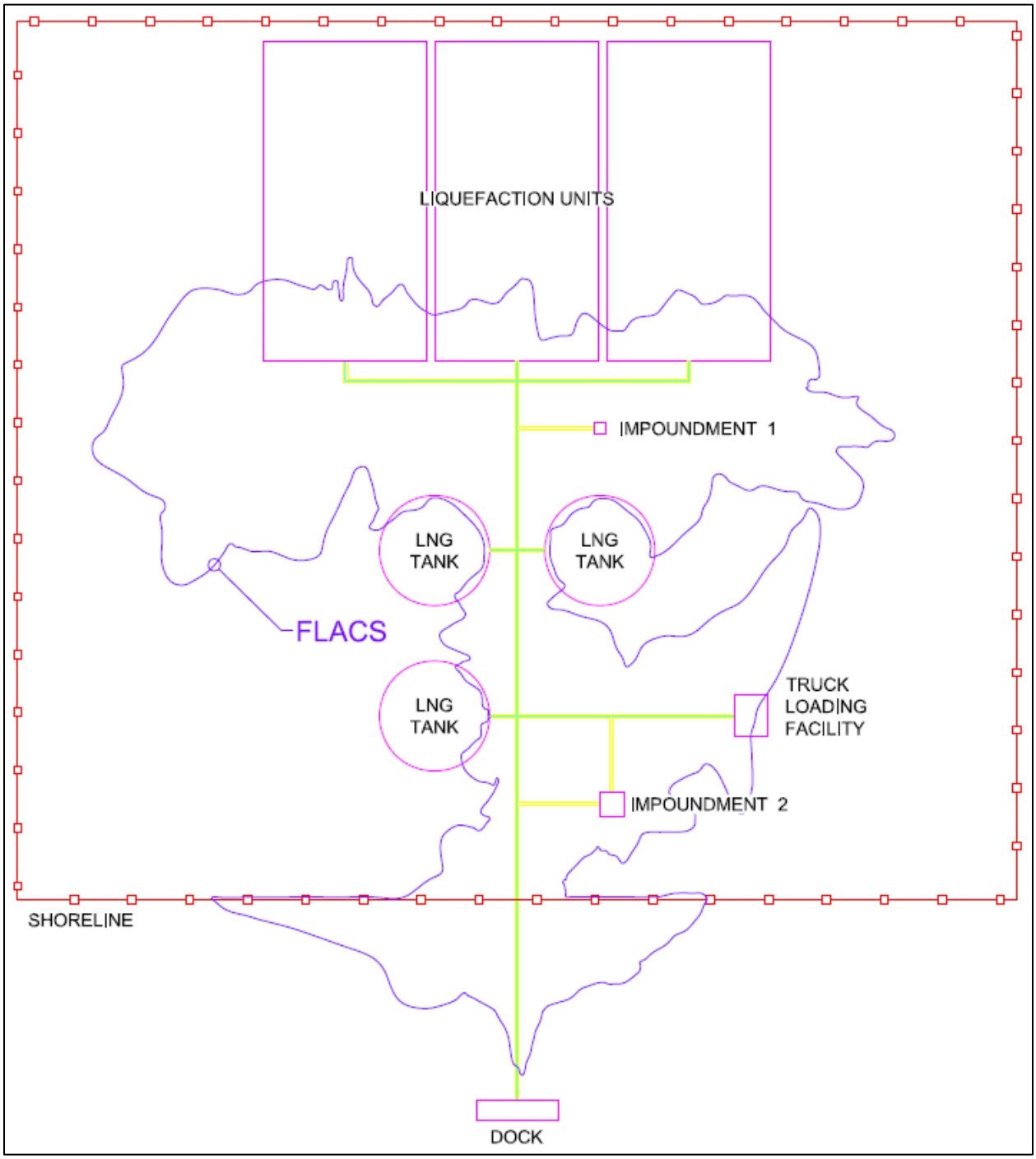

Figure 21.2-5: Rundown Line (1 m/s, 0.01m)

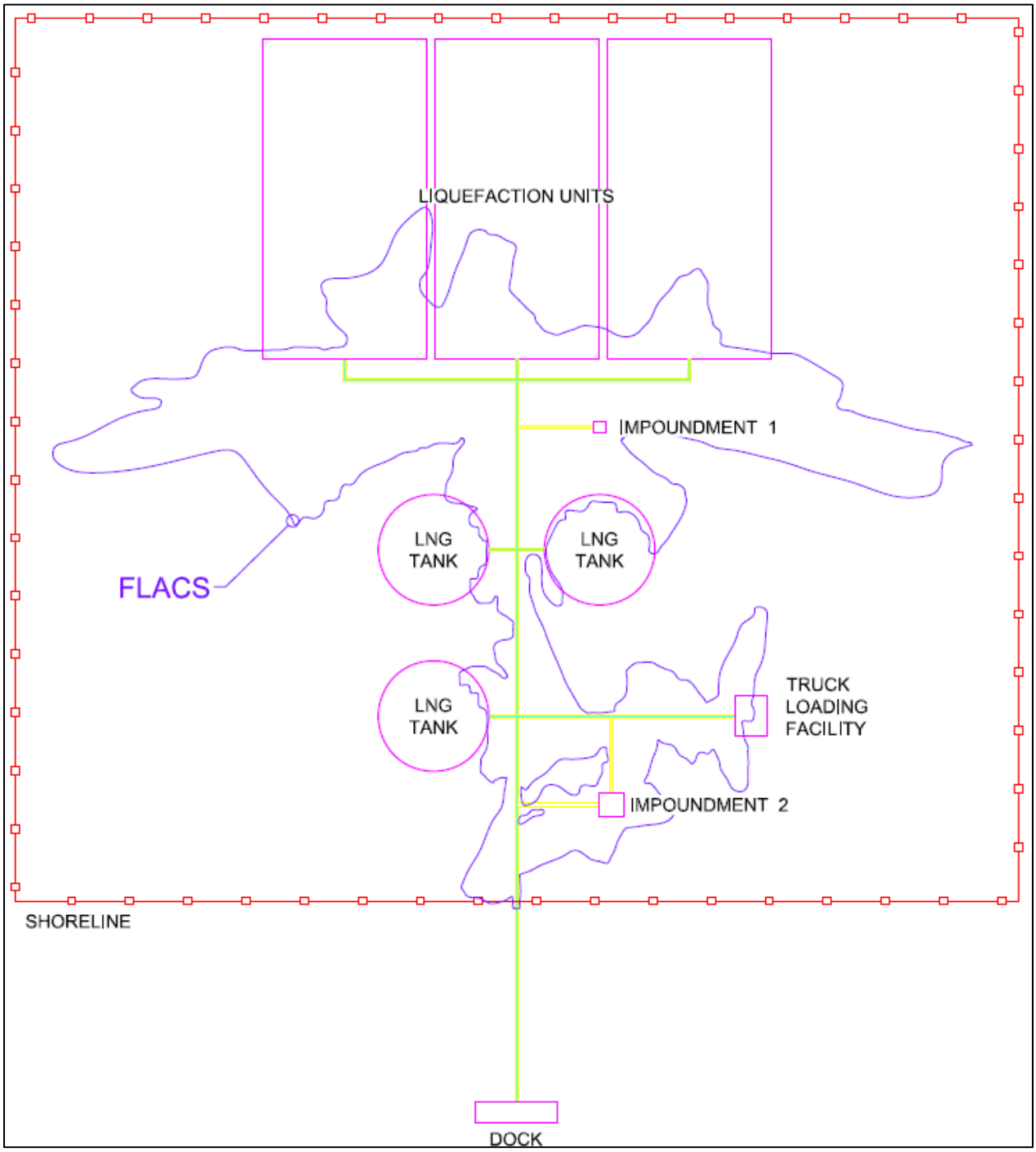

Figure 21.2-6: Rundown Header (2 m/s, 0.03m)

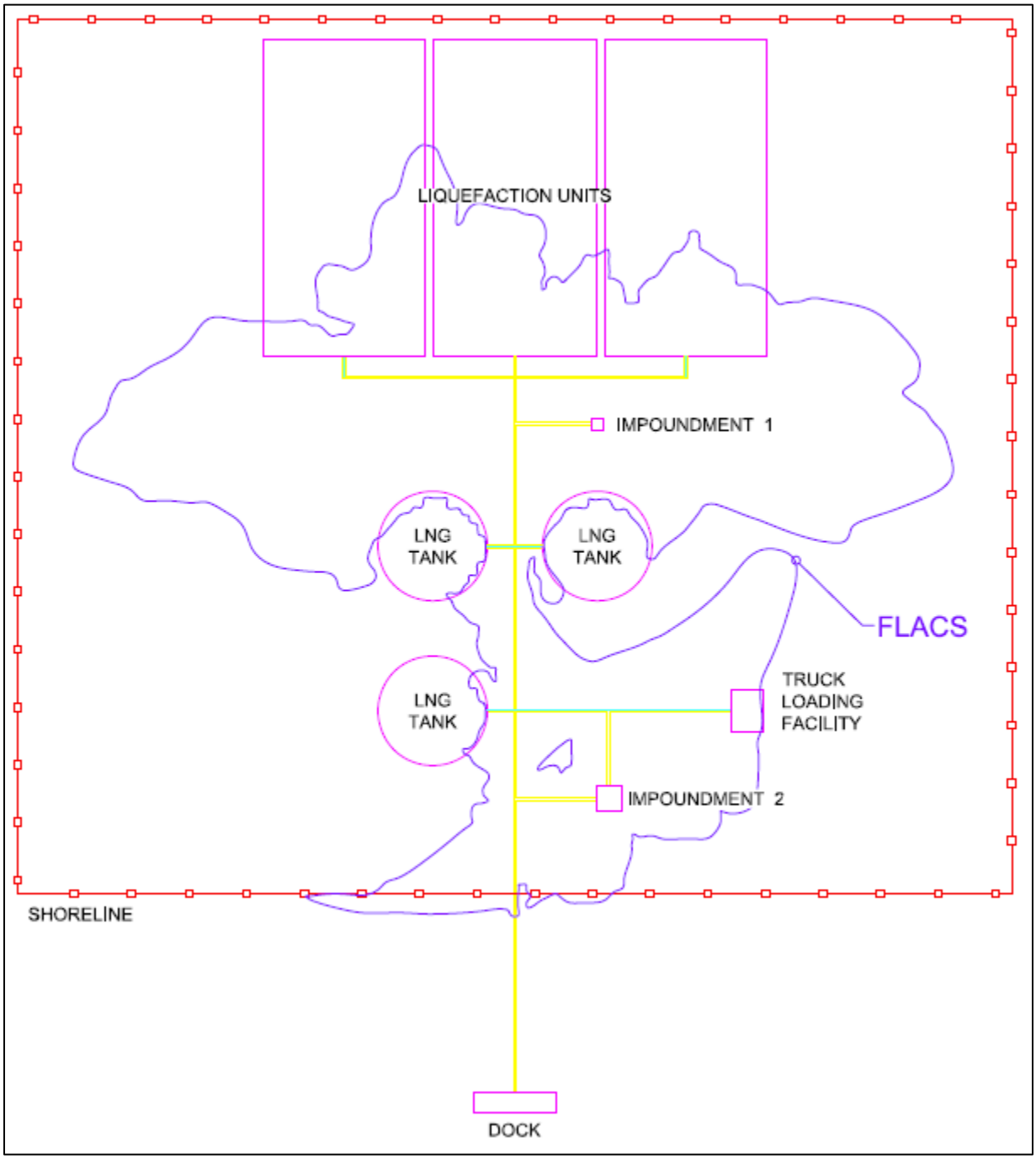

Figure 21.2-7: Rundown Header (1 m/s, 0.03m)

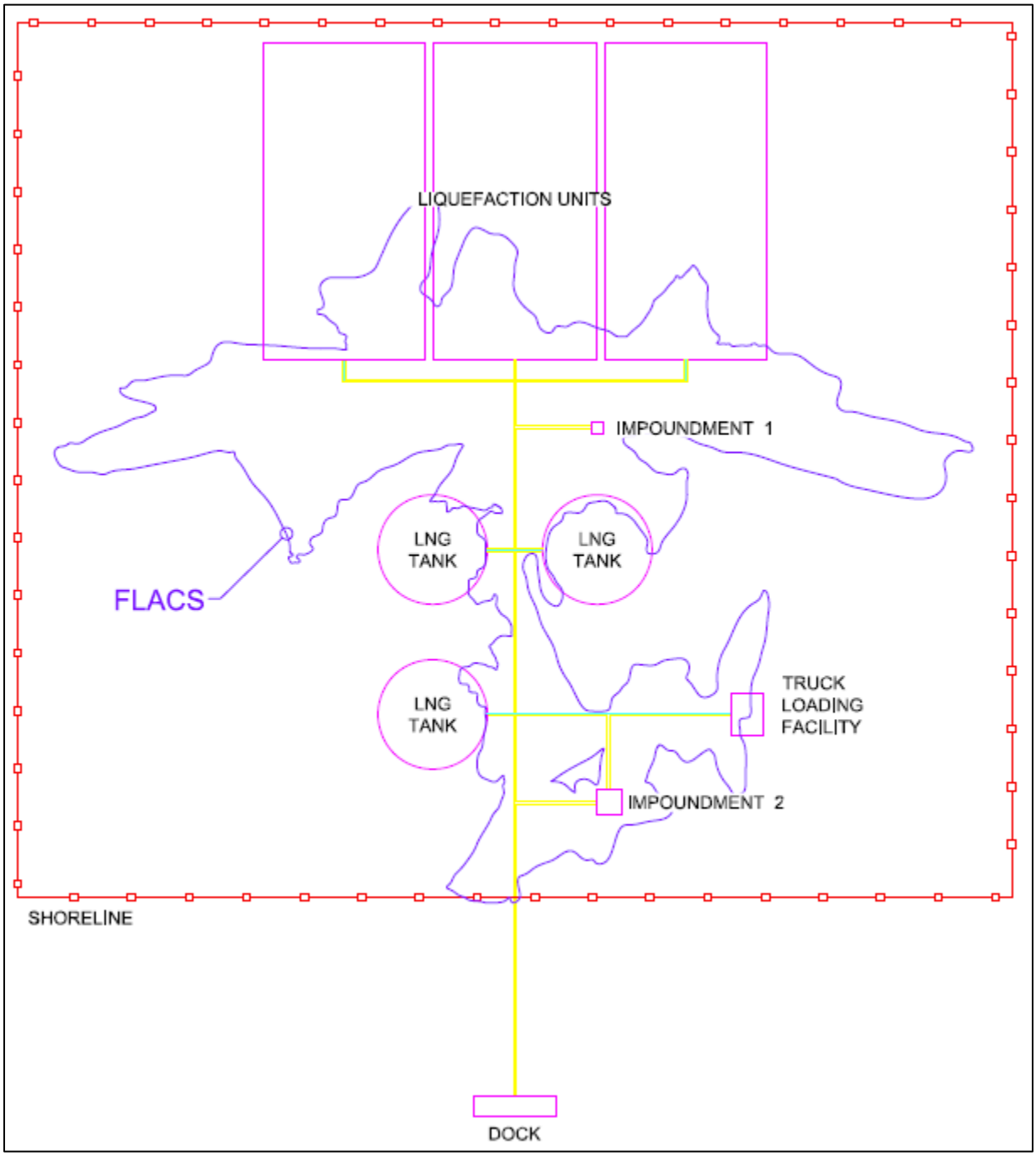

Figure 21.2-8: Rundown Header (2 m/s, 0.01m)

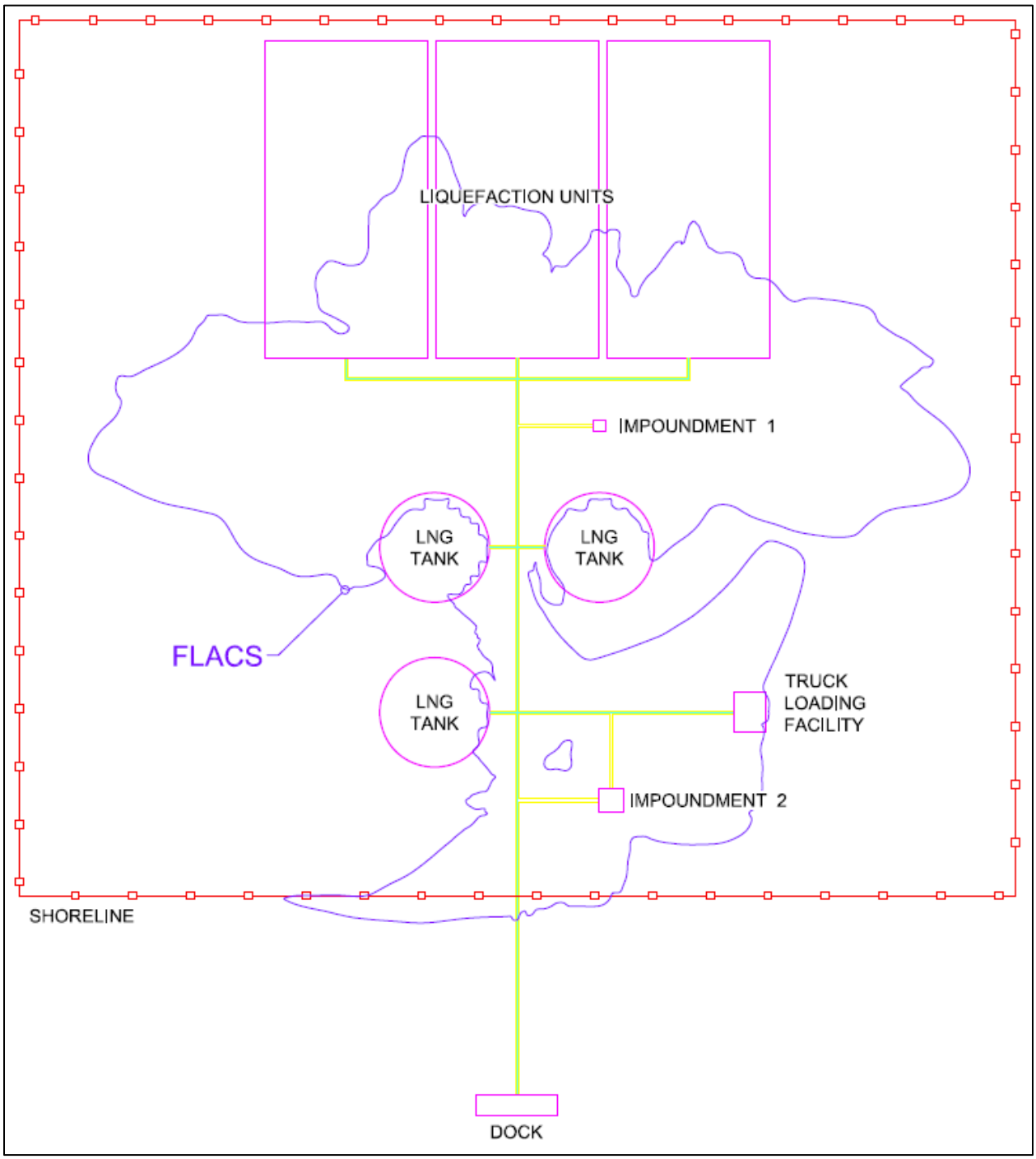

Figure 21.2-9: Rundown Header (1 m/s, 0.01m)

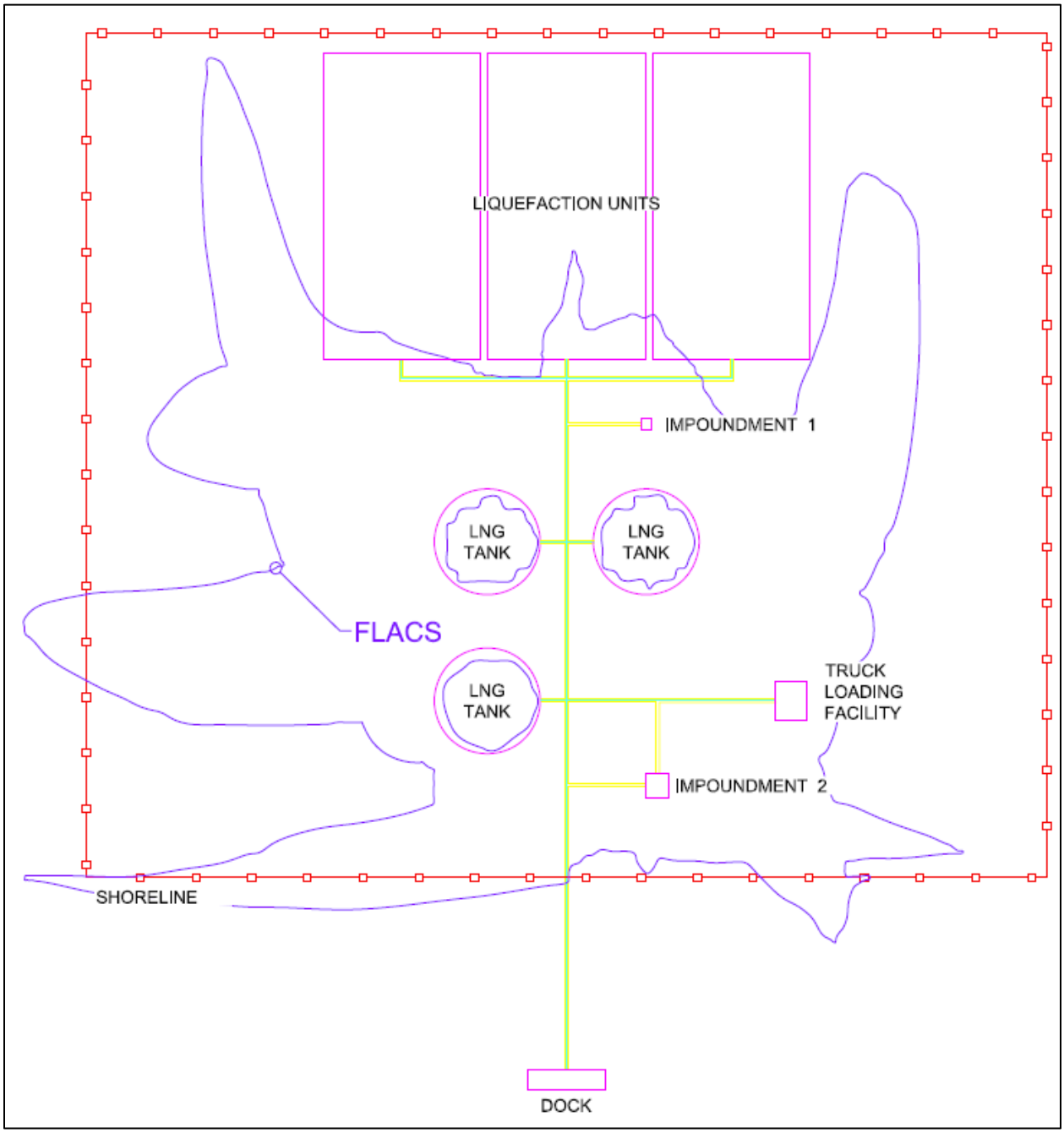

Figure 21.2-10: Marine Loading Line at Storage Tank (2 m/s, 0.03m)

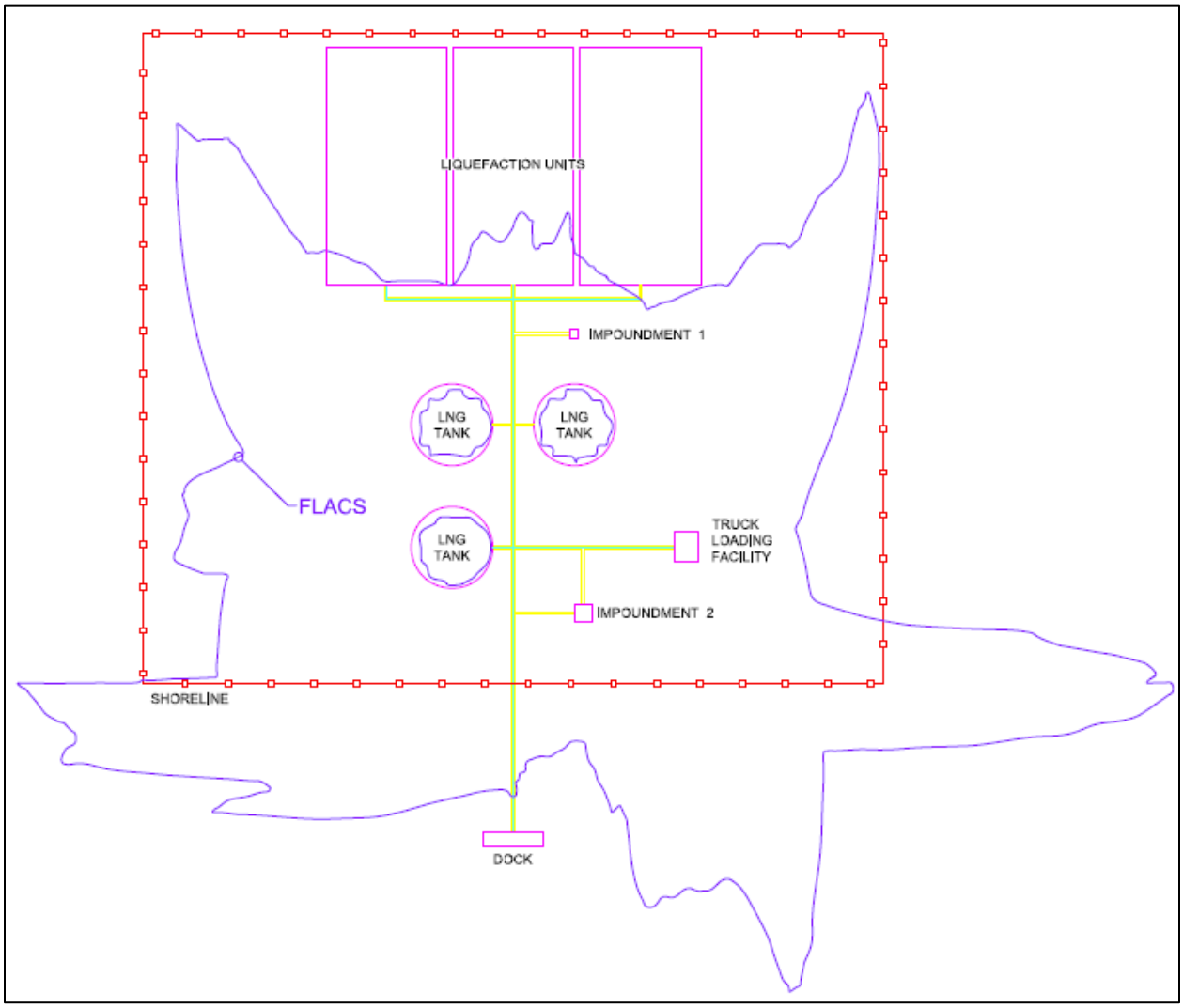

Figure 21.2-11: Marine Loading Line at Storage Tank (1 m/s, 0.03m)

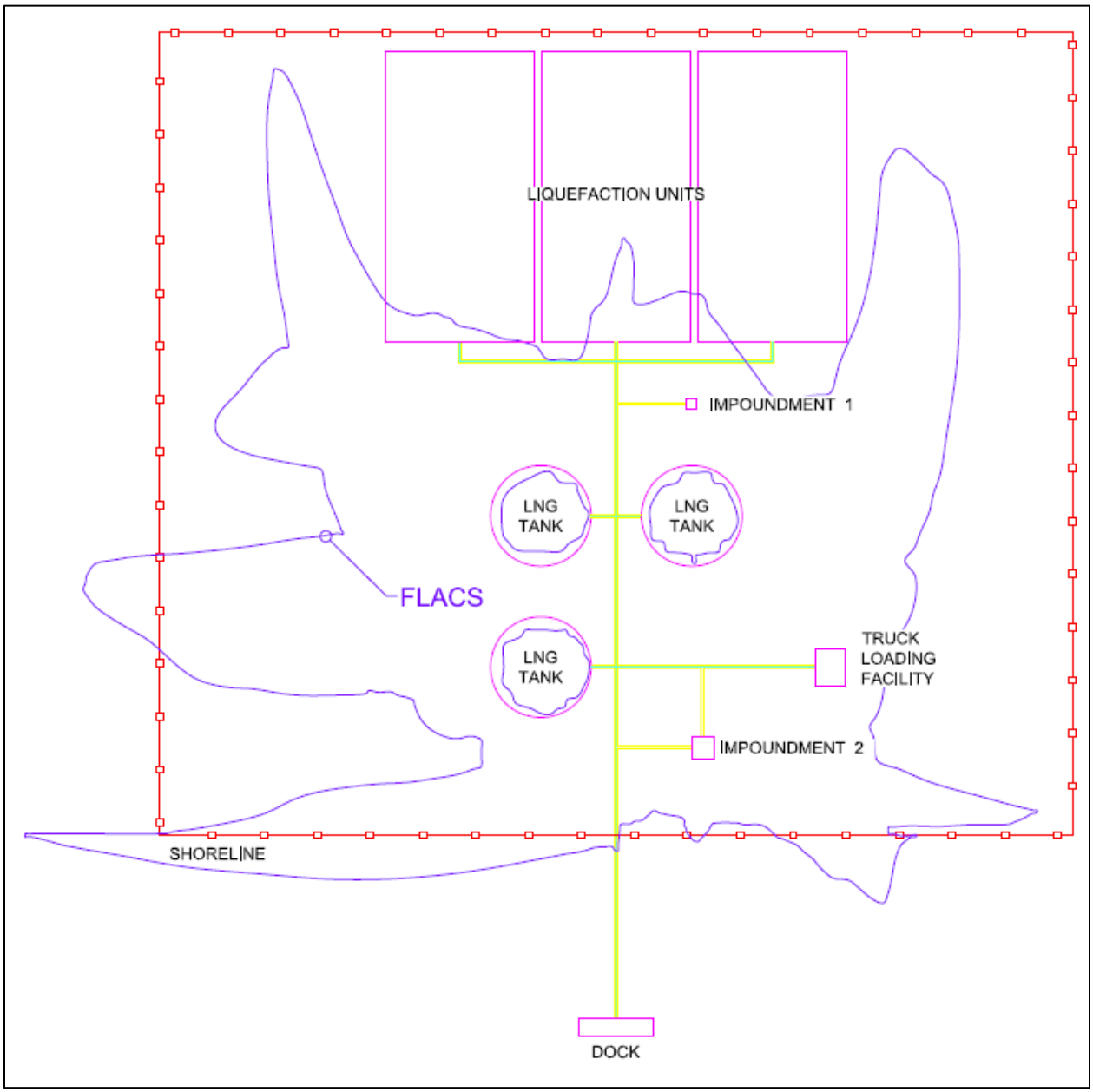

Figure 21.2-12: Marine Loading Line at Storage Tank (2 m/s, 0.01m)

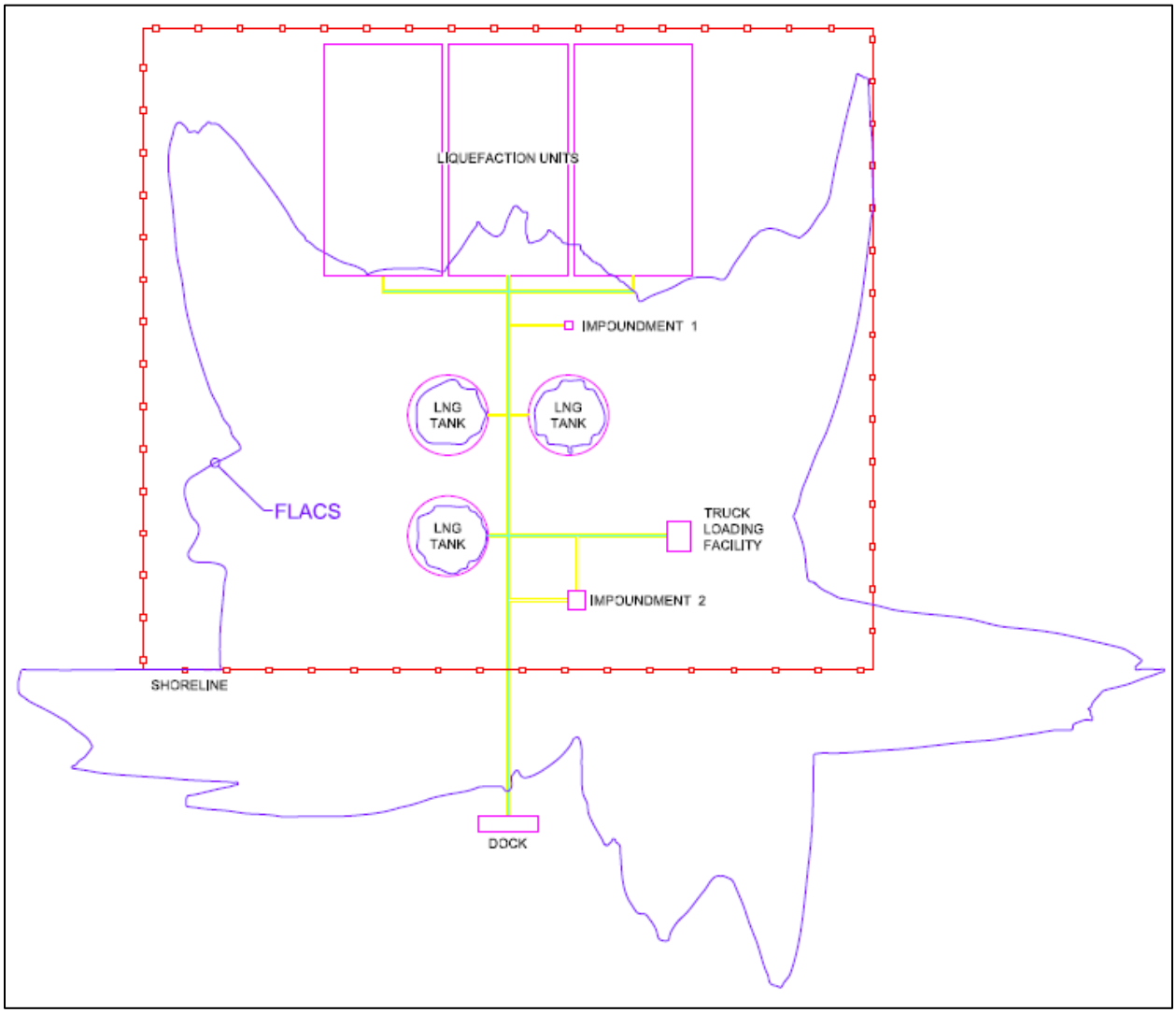

Figure 21.2-13: Marine Loading Line at Storage Tank (1 m/s, 0.01m)

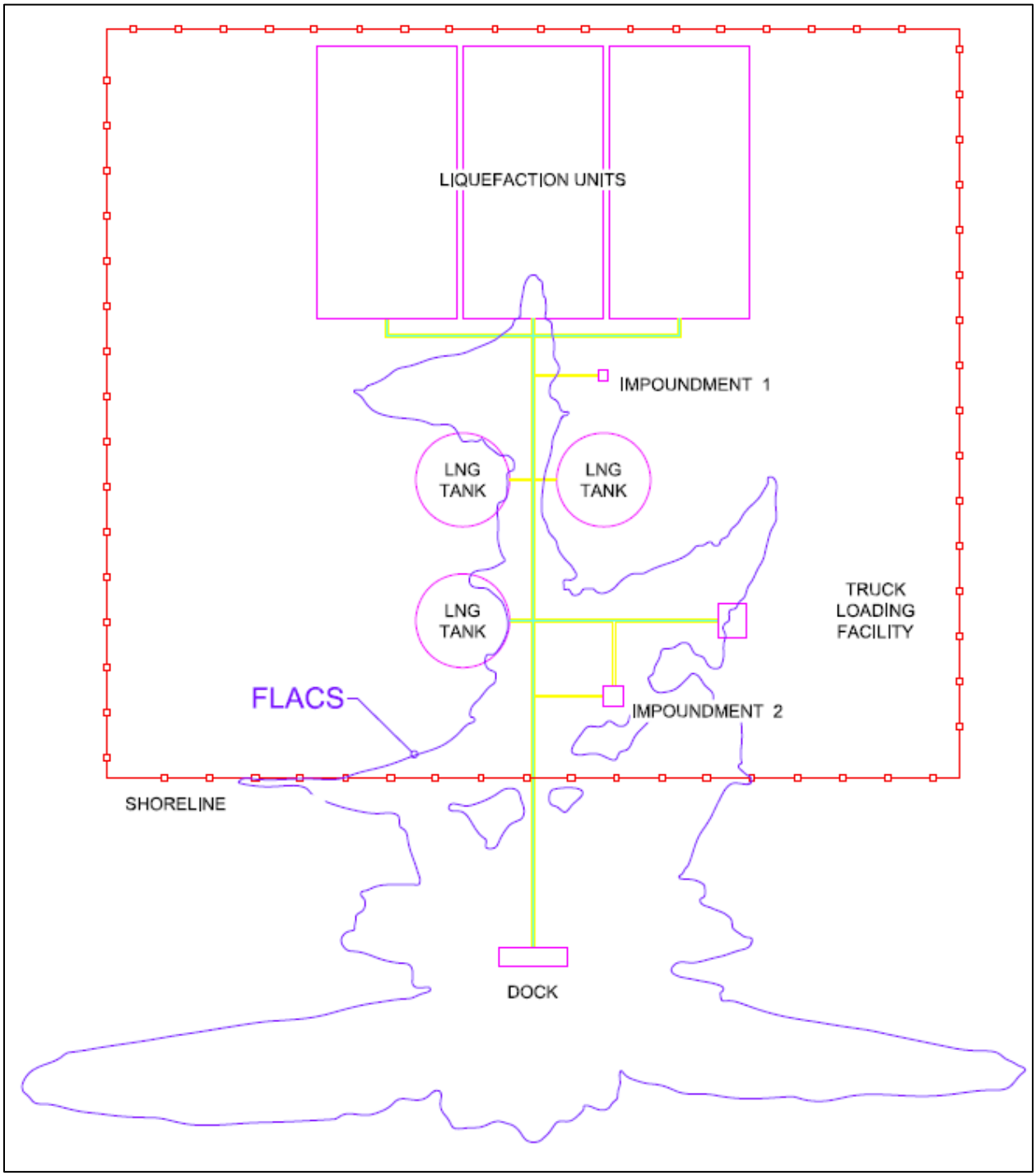

Figure 21.2-14: Marine Loading Line at Jetty (2 m/s, 0.03m)

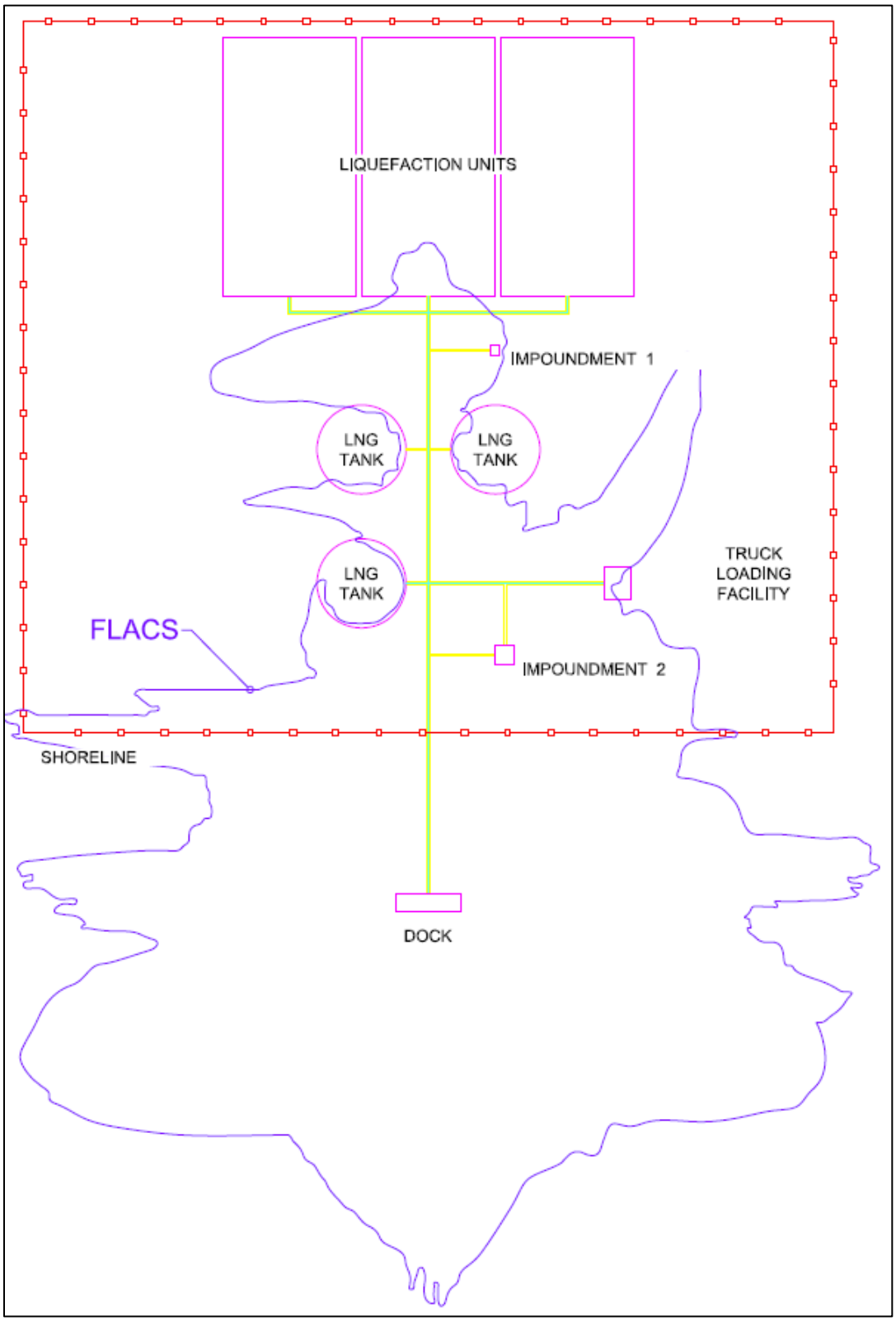

Figure 21.2-15: Marine Loading Line at Jetty (1 m/s, 0.03m)

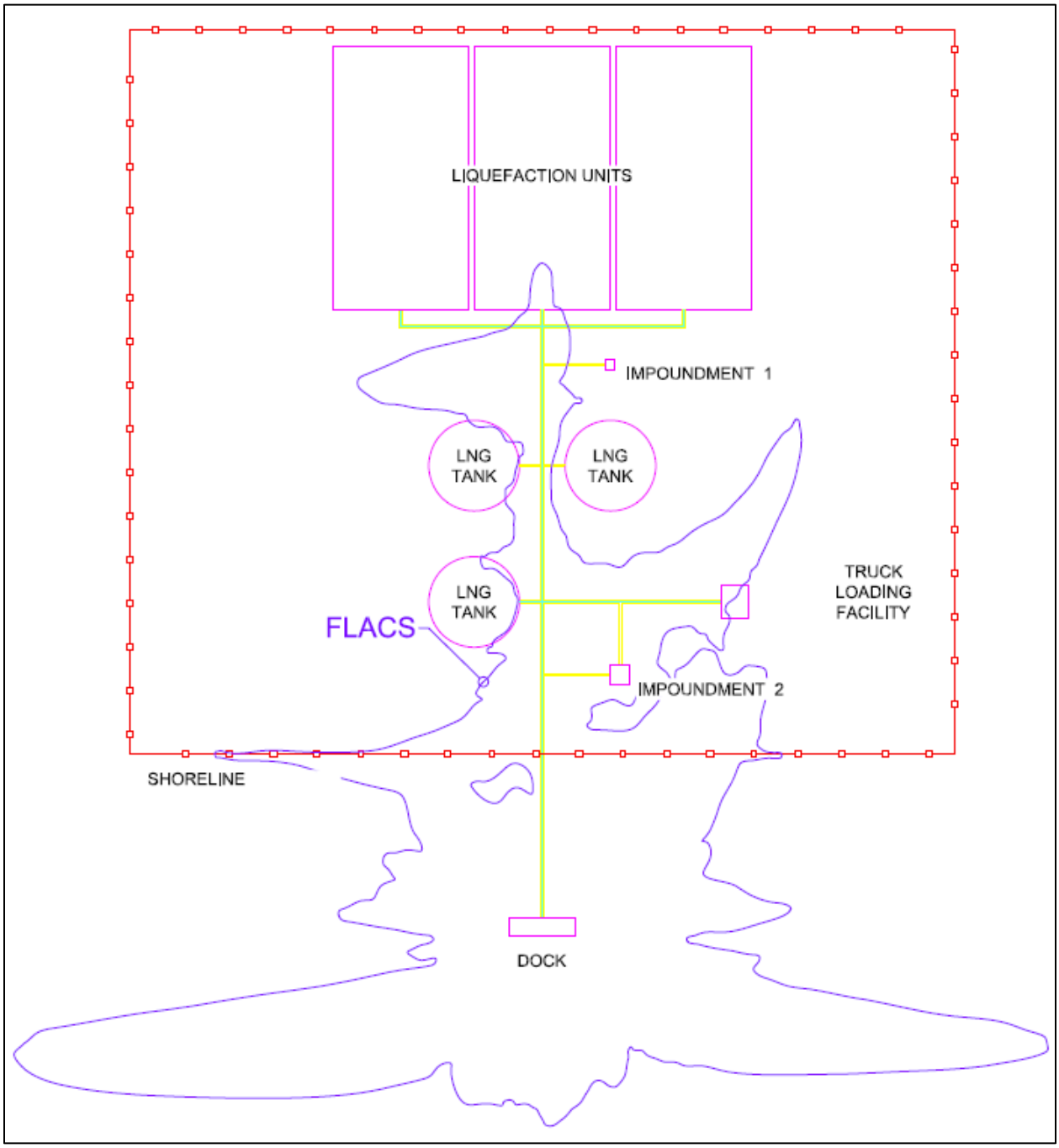

Figure 21.2-16: Marine Loading Line at Jetty (2 m/s, 0.01m)

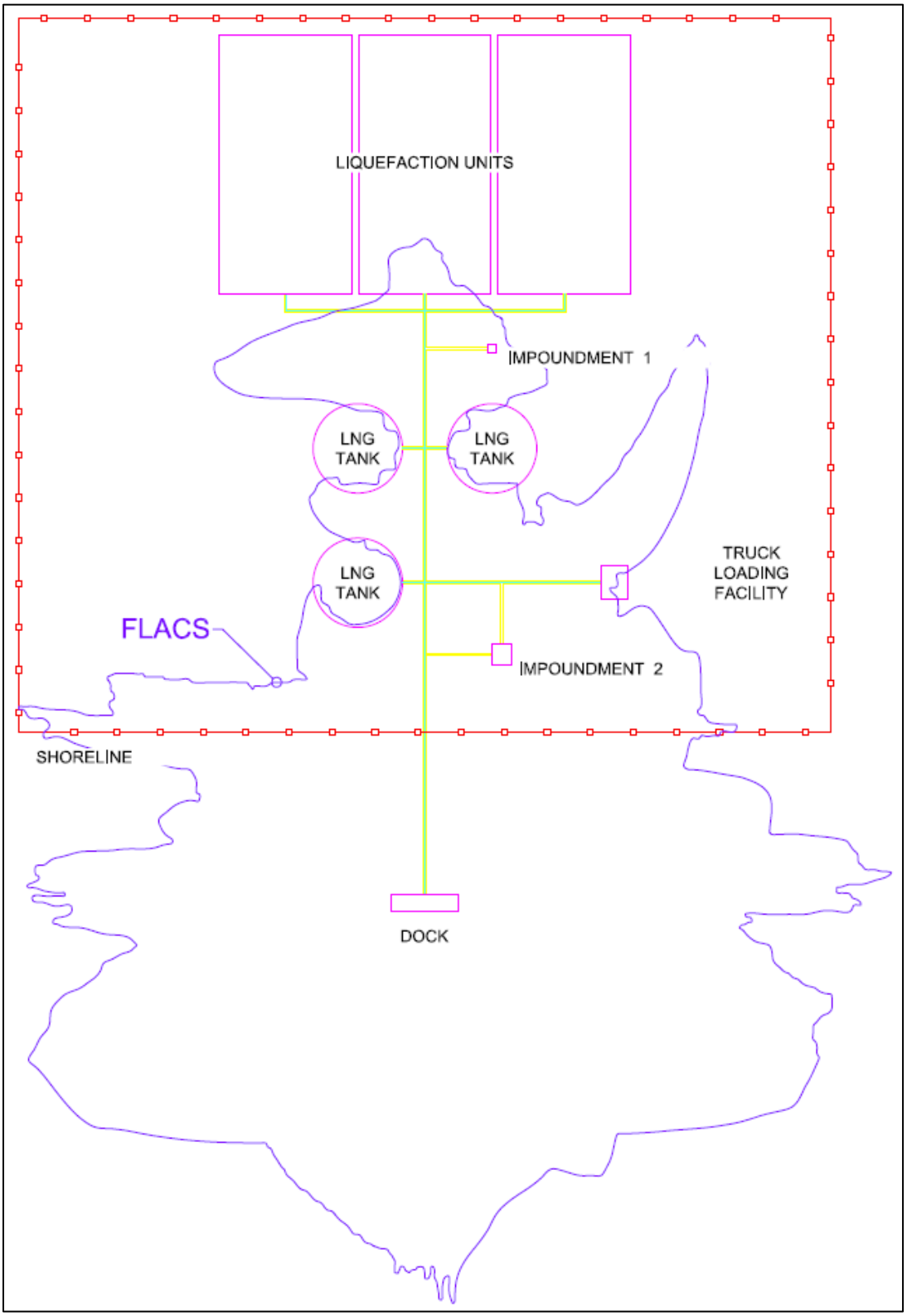

Figure 21.2-17: Marine Loading Line at Jetty (1 m/s, 0.01m)

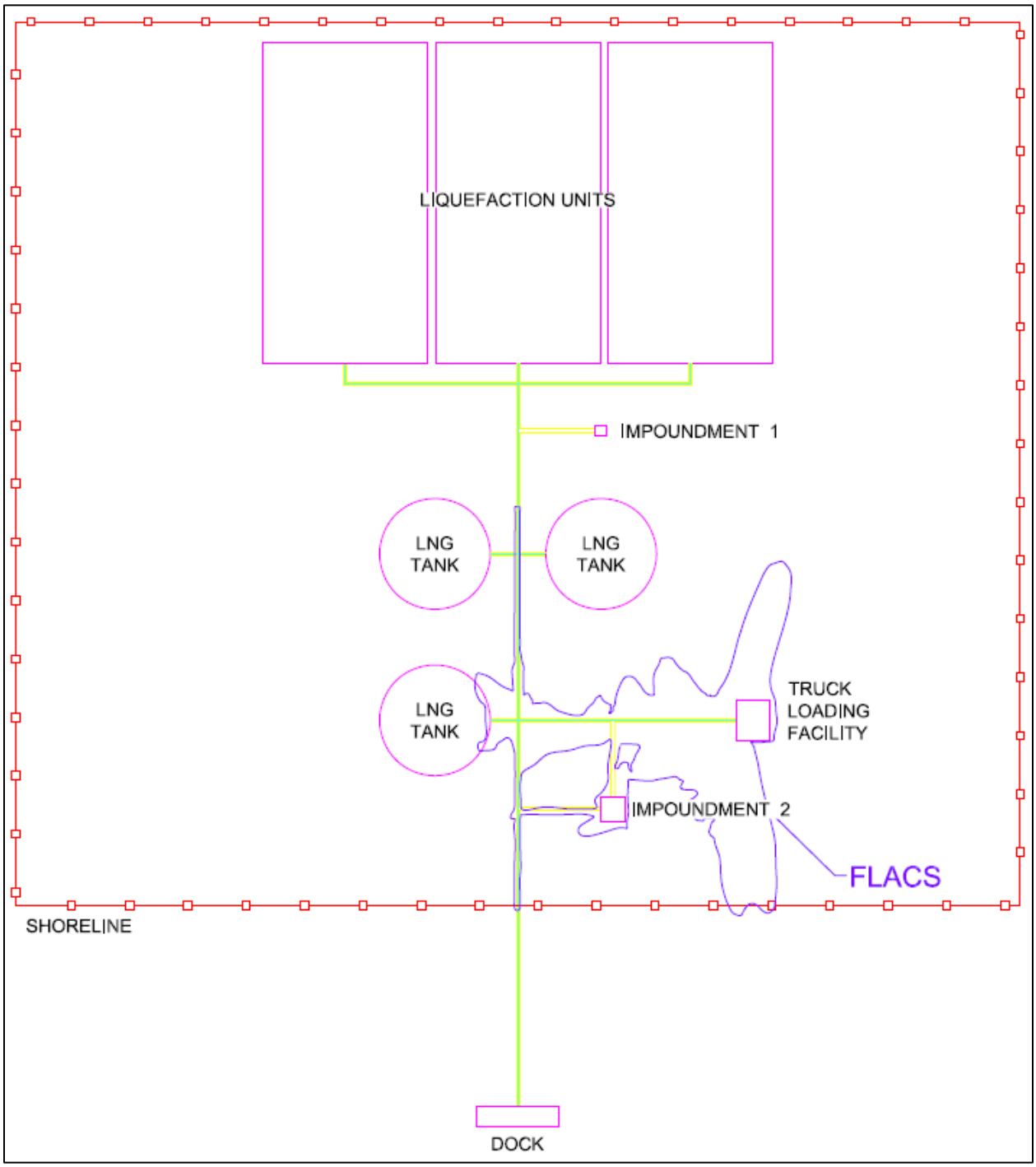

Figure 21.2-18: Truck Loading Line (2 m/s, 0.03m)

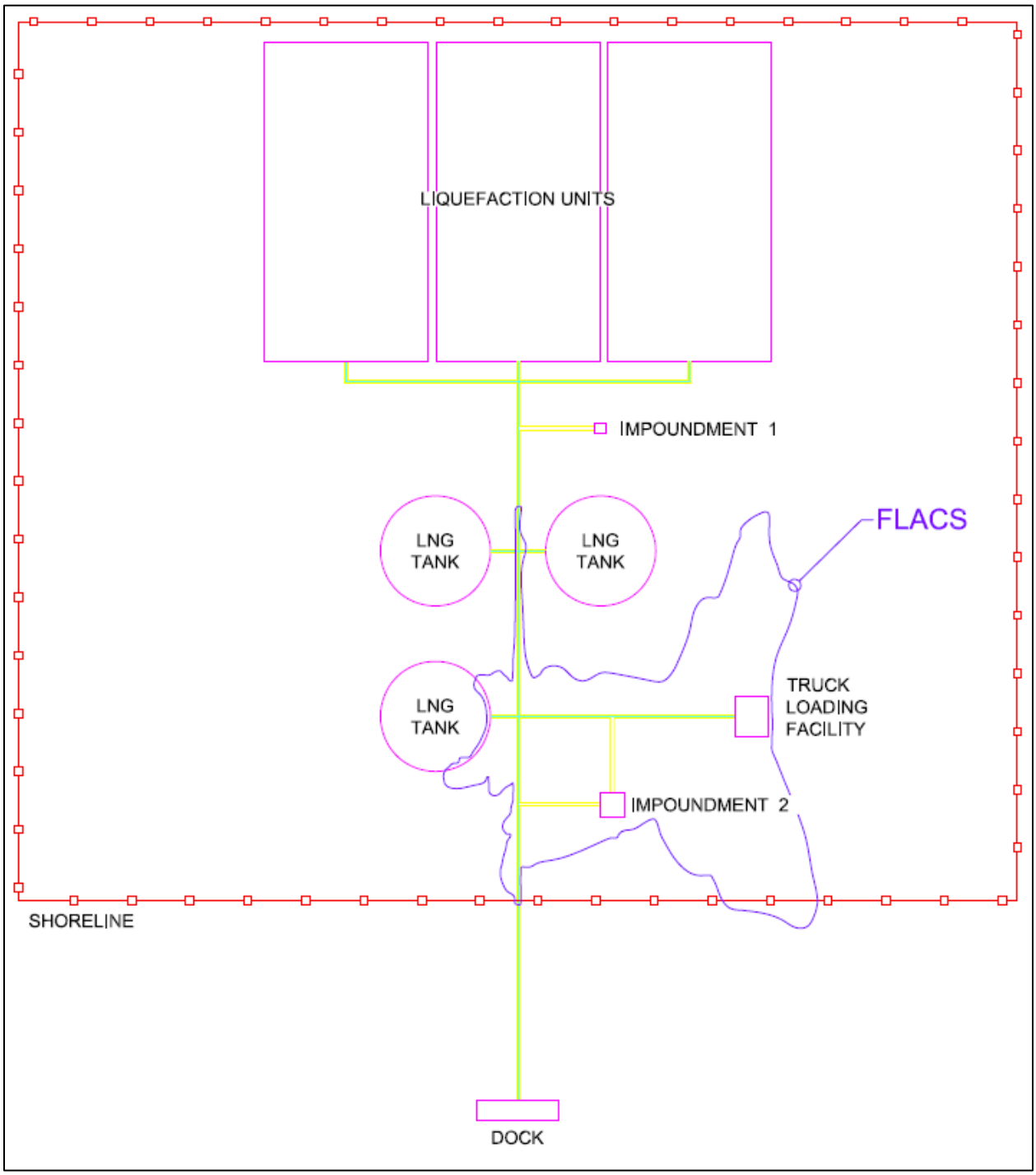

Figure 21.2-19: Truck Loading Line (1 m/s, 0.03m)

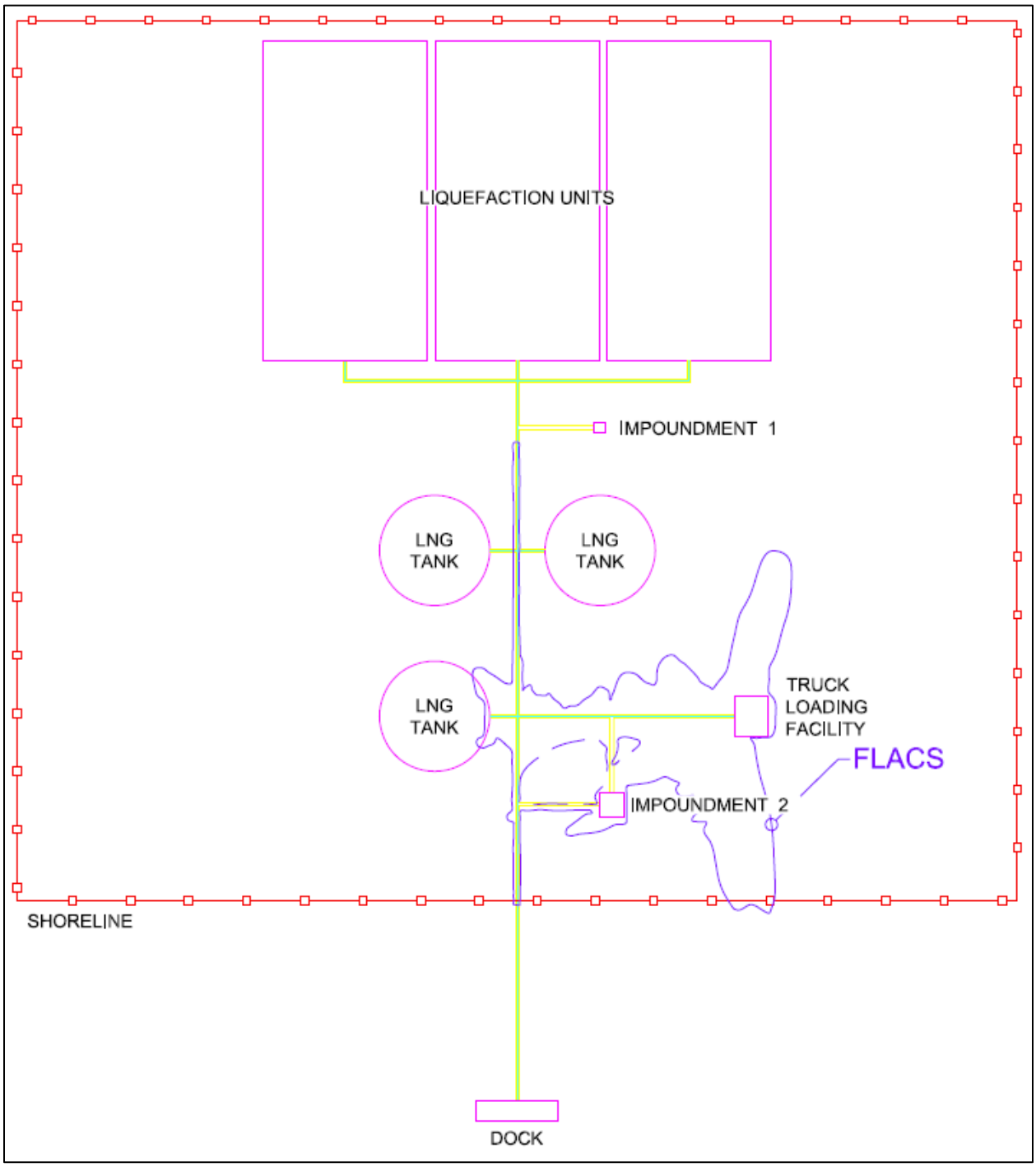

Figure 21.2-20: Truck Loading Line (2 m/s, 0.01m)

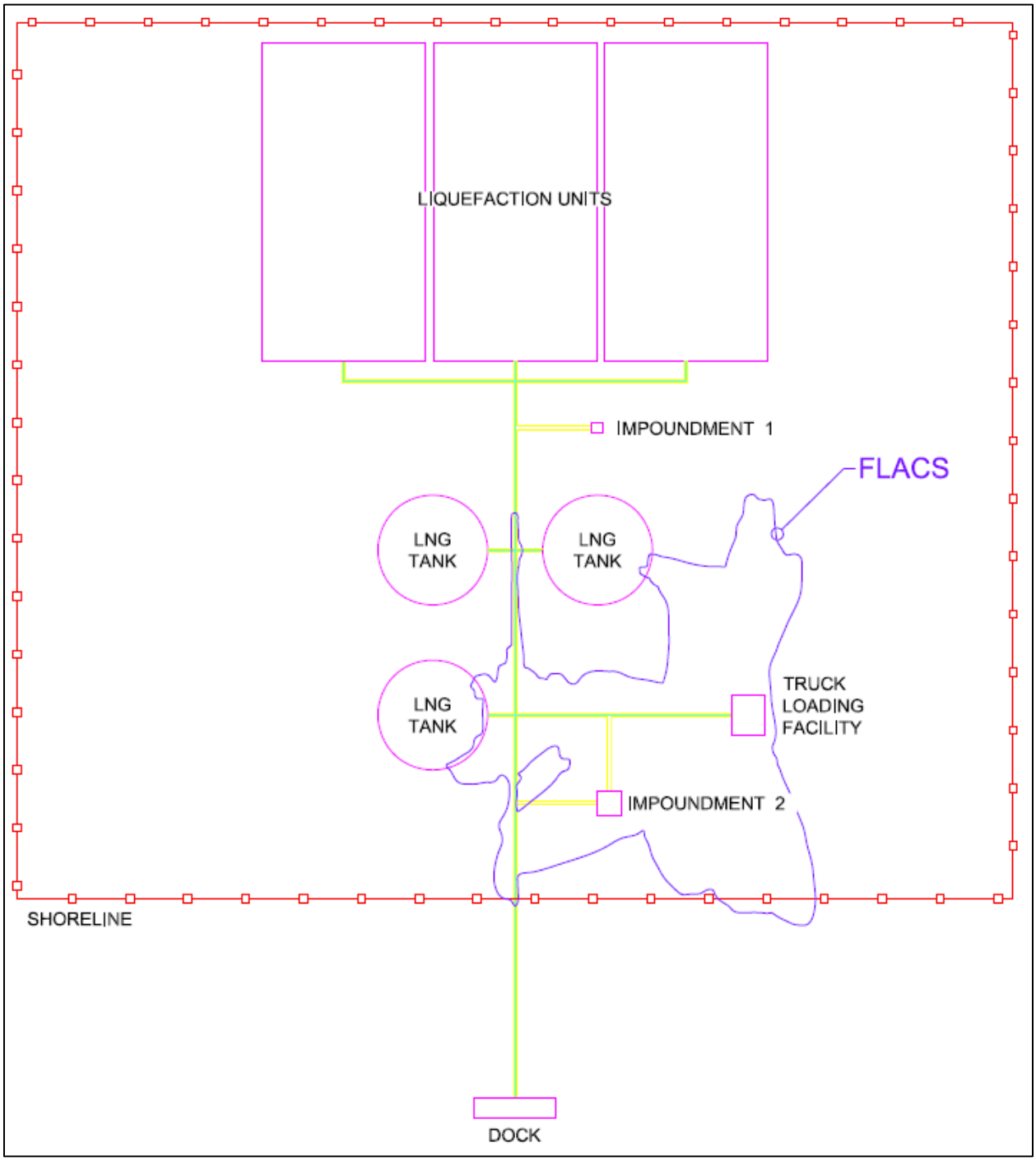

Figure 21.2-21: Truck Loading Line (1 m/s, 0.01m)

Results Discussion:

The FLACS results illustrated in each figure for the different wind speed and surface roughness values are for a single release into the spill containment system, which flows into the impoundment. The results presented are combined results for winds blowing in the North, South, East and West directions.

The majority of the releases stay within the plant property line. The releases that extend beyond the facility property line can be mitigated with basic design optimizations.

All conveyance scenarios have significantly smaller vapor dispersion exclusion zones compared to the jetting and flashing exclusion zones.

21.3 LNG Impoundments

The design spills used as the basis for LNG spills into impoundments are detailed in Table 21.3-1.

Table 21.3-1: LNG Impoundments Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10-Minute Spill Volume (ft^3)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)	Impoundment #
Rundown Header (E-6)	3,697,796	7,499	28 x 28 x 29	22,736	1
Marine Loading Line at Storage Tank (E-11)	8,644,638	70,630	60 x 60 x 20	72,000	2

Figure 21.3-1 illustrates the release location for the worst case scenarios described in Table 21.3-1:

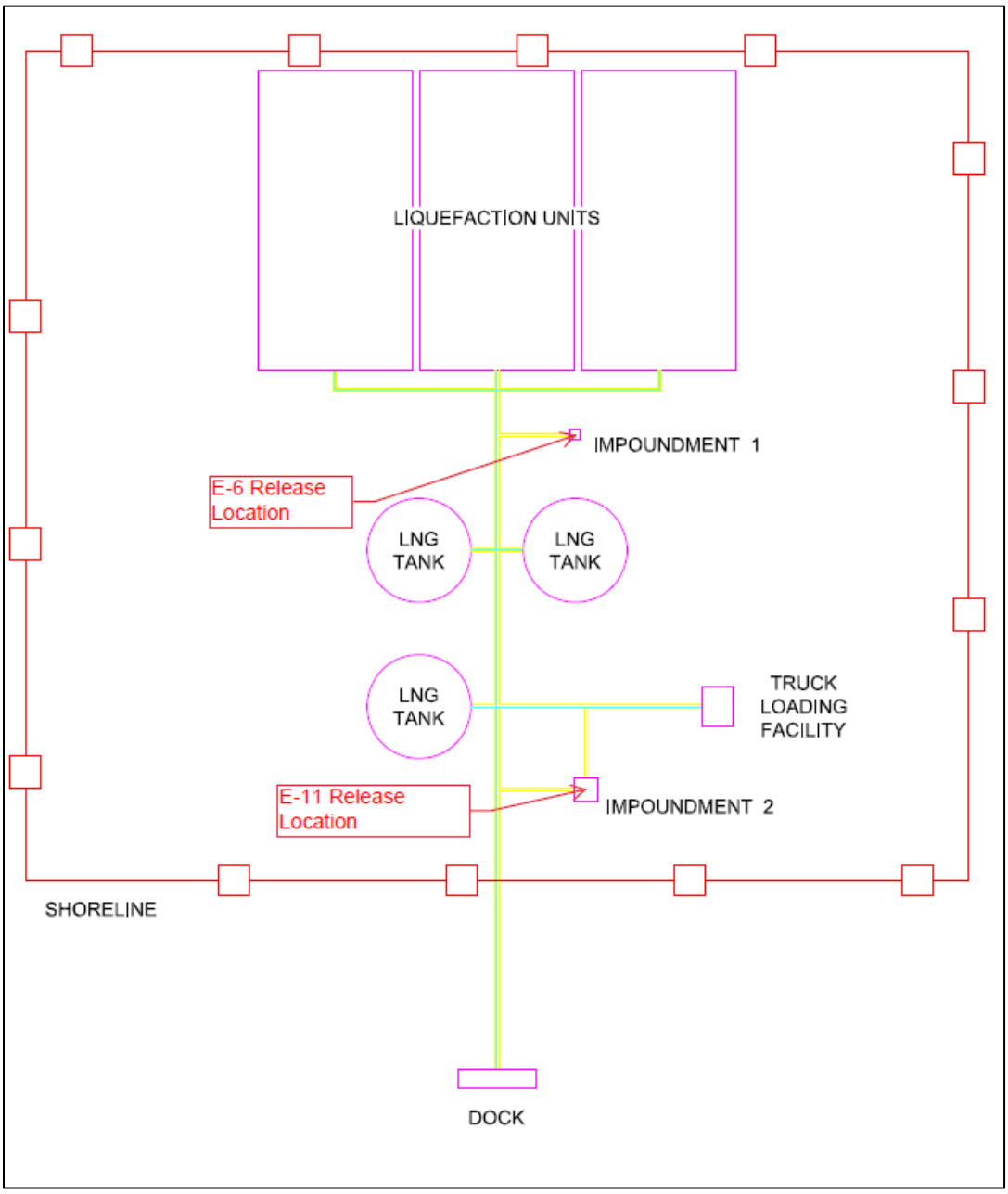

Figure 21.3-1: Impoundment Release Locations

The results of the LNG impoundment vapor dispersion modeling are detailed in Table 21.3-2.

Table 21.3-2: LNG Impoundments Vapor Dispersion Results

Impoundment Location	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast ½ LFL Distance (ft)	DEGADIS ½ LFL Distance (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)
Rundown Header (E-6)	2	0.03	1,508.70	597.60	344.49
Rundown Header (E-6)	1	0.03	1,907.10	582.45	410.11
Rundown Header (E-6)	2	0.01	1,661.67	659.65	N/A
Rundown Header (E-6)	1	0.01	2,118.85	653.12	N/A
Marine Loading Line at Storage Tank (E-11)	2	0.03	3,202.07	1,397.46	157.48
Marine Loading Line at Storage Tank (E-11)	1	0.03	3,884.81	1,343.87	351.05
Marine Loading Line at Storage Tank (E-11)	2	0.01	3,463.43	1,527.30	N/A
Marine Loading Line at Storage Tank (E-11)	1	0.01	4,300.33	1,473.96	N/A

The results of the LNG impoundment vapor dispersion modeling are illustrated in the following figures:

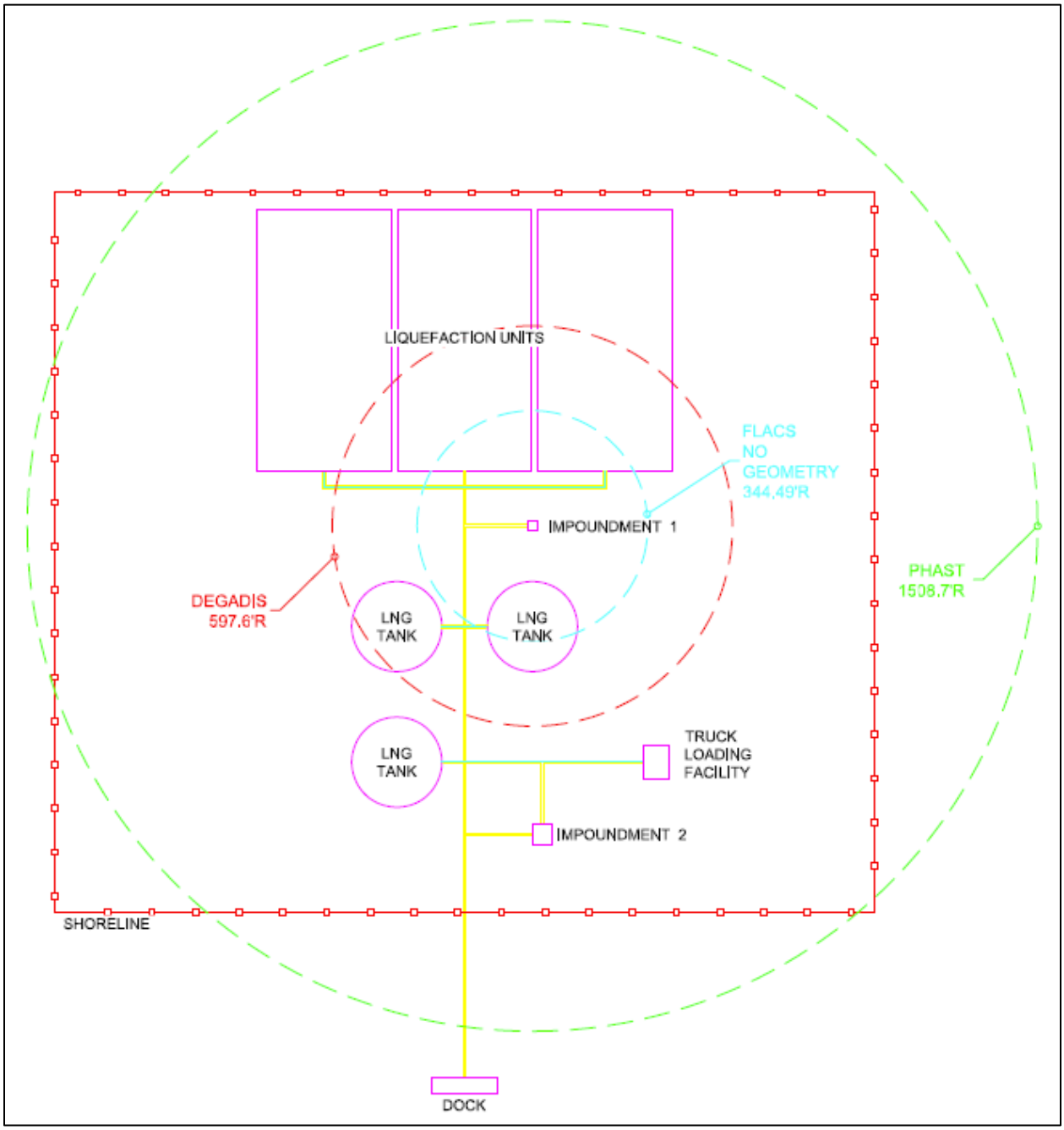

Figure 21.3-2: Rundown Header (2 m/s, 0.03m)

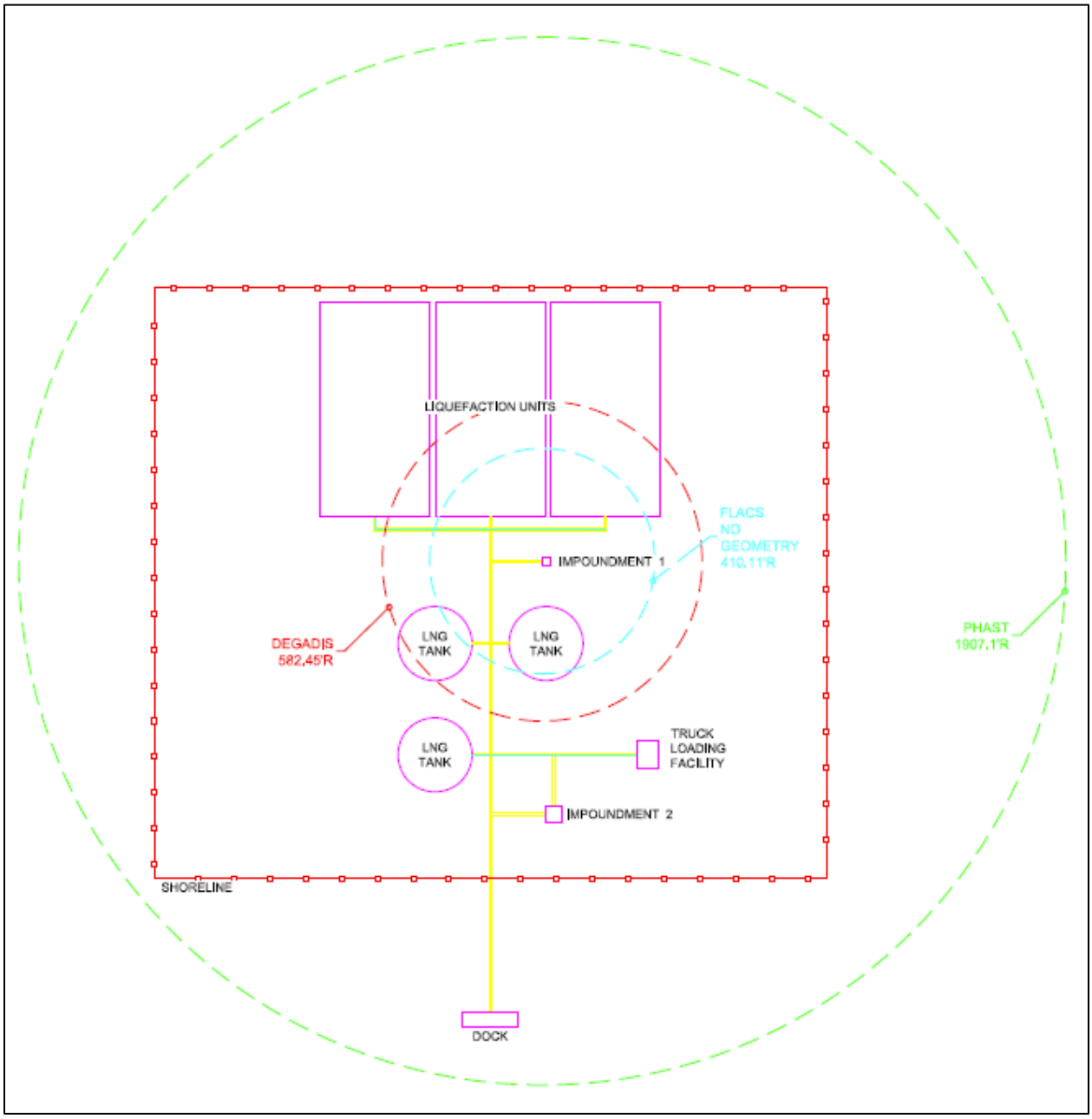

Figure 21.3-3: Rundown Header (1 m/s, 0.03m)

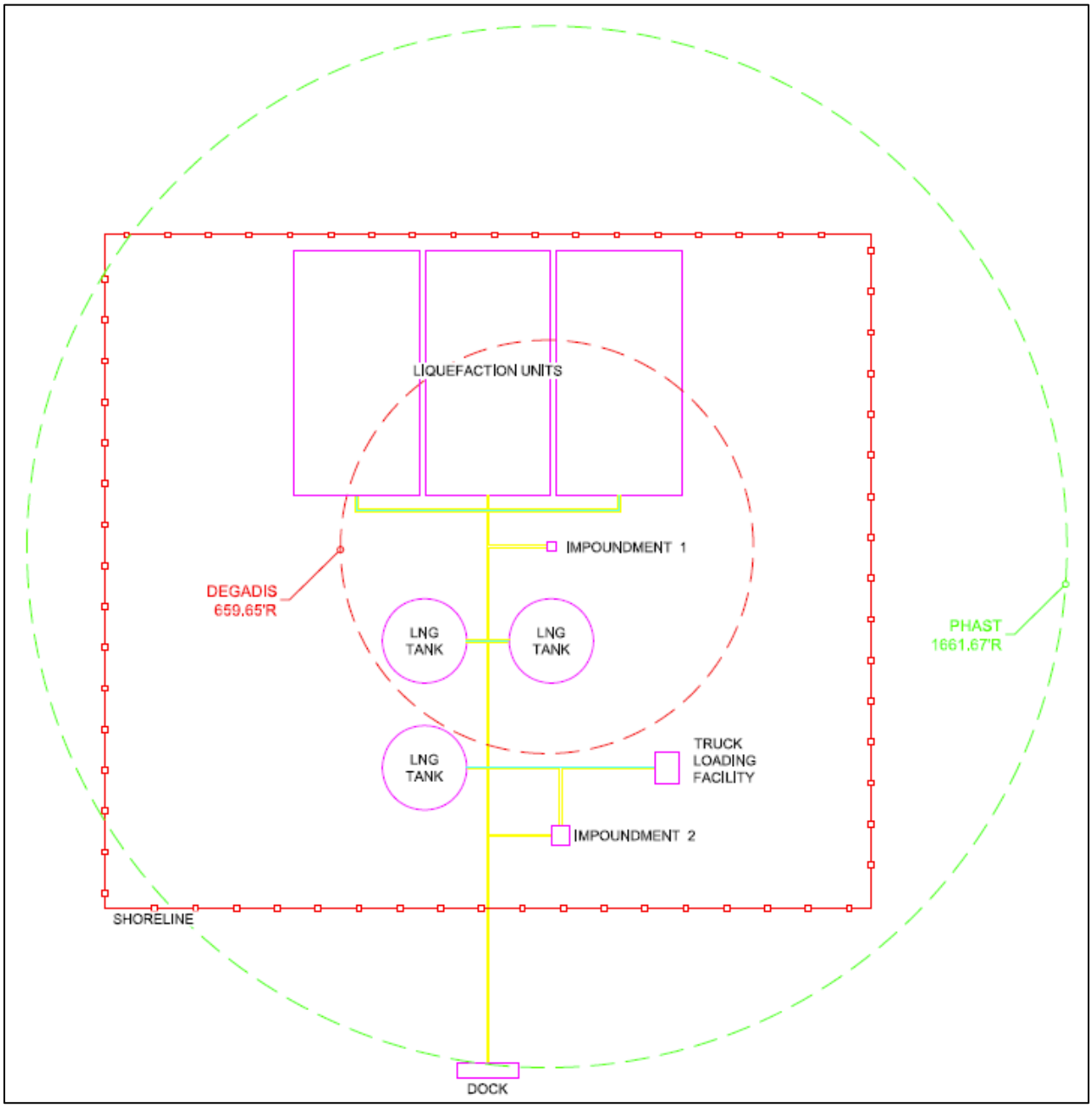

Figure 21.3-4: Rundown Header (2 m/s, 0.01m)

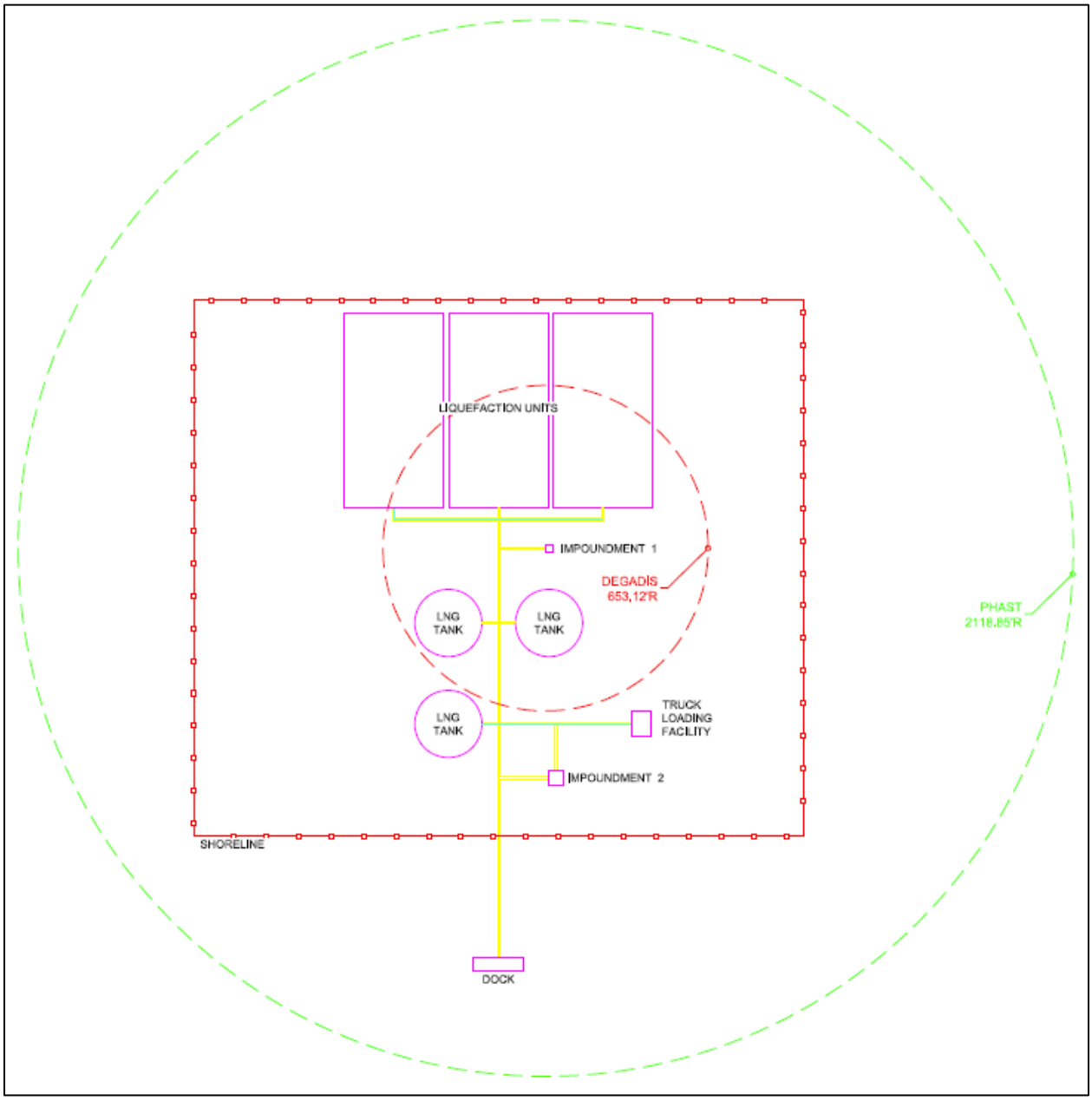

Figure 21.3-5: Rundown Header (1 m/s, 0.01m)

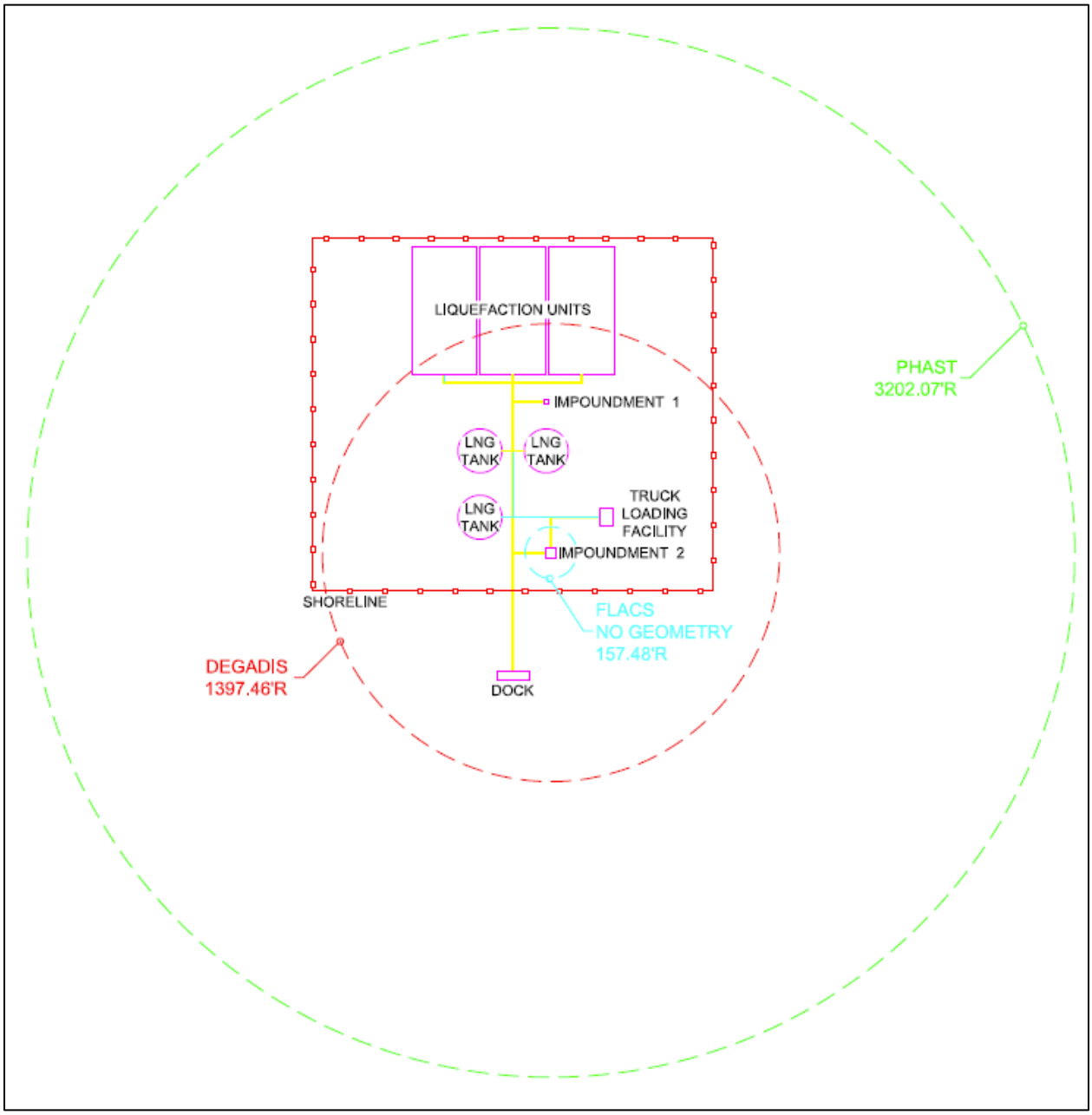

Figure 21.3-6: Marine Loading Line at Storage Tank (2 m/s, 0.03m)

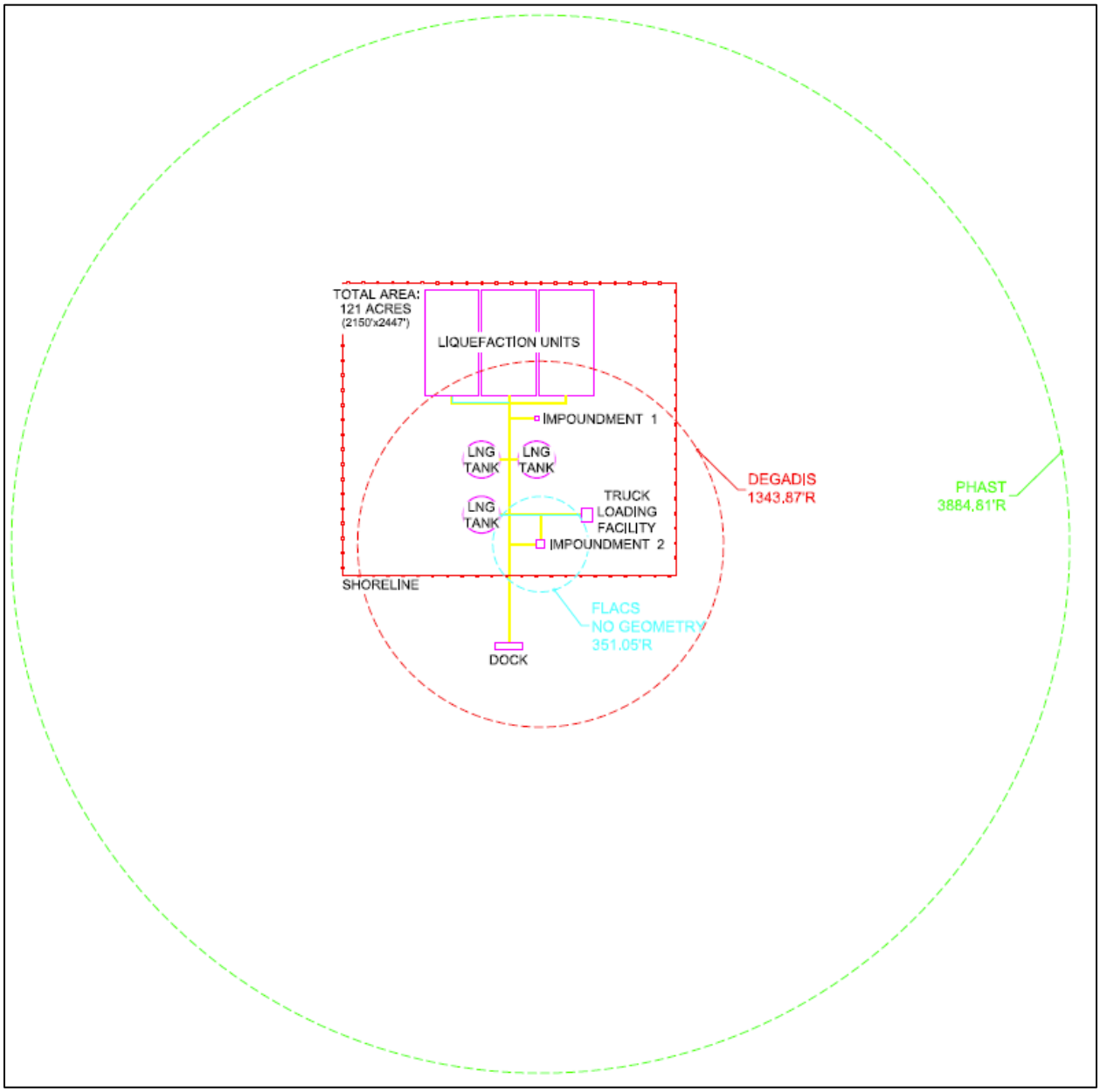

Figure 21.3-7: Marine Loading Line at Storage Tank (1 m/s, 0.03m)

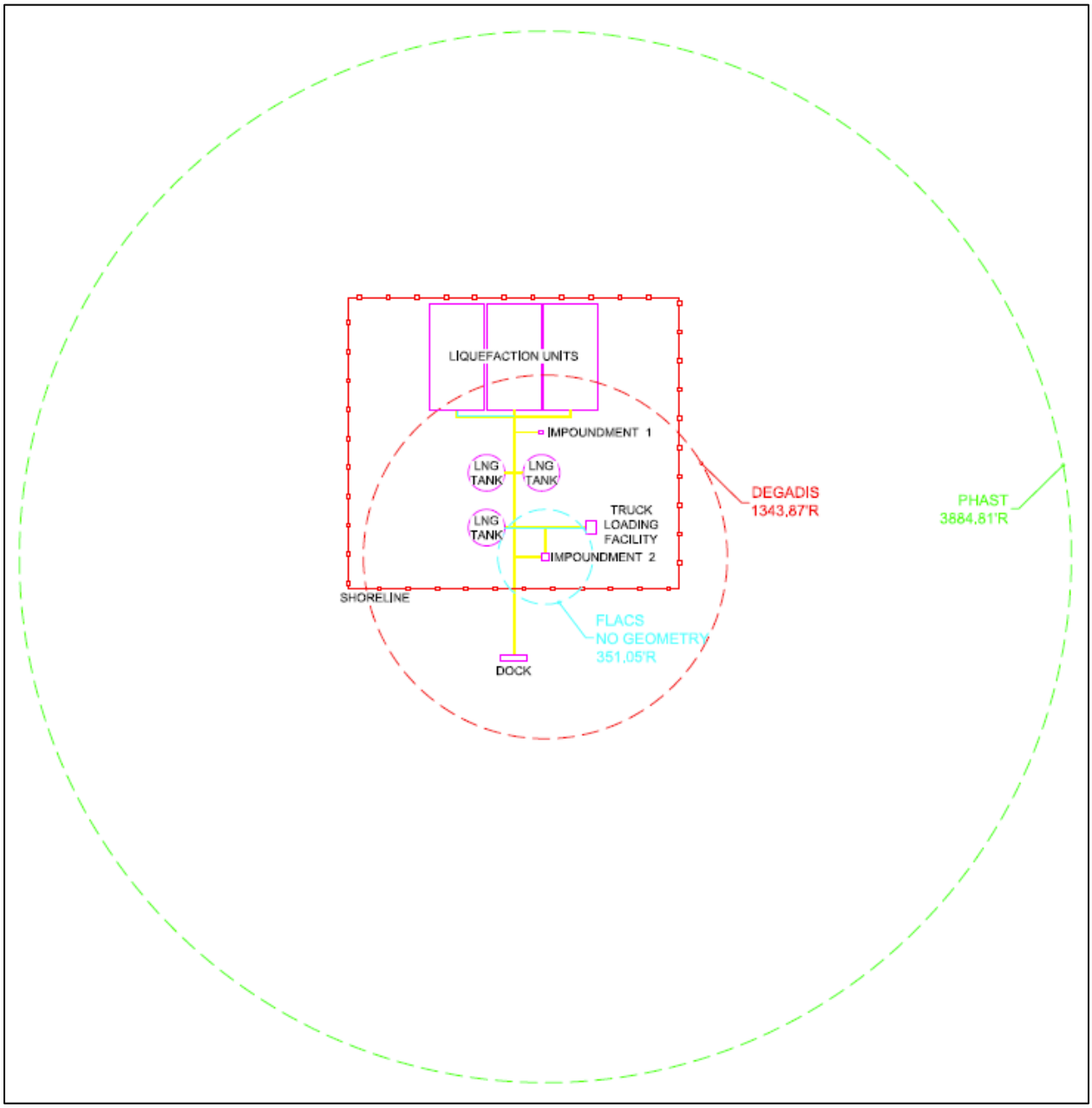

Figure 21.3-8: Marine Loading Line at Storage Tank (2 m/s, 0.01m)

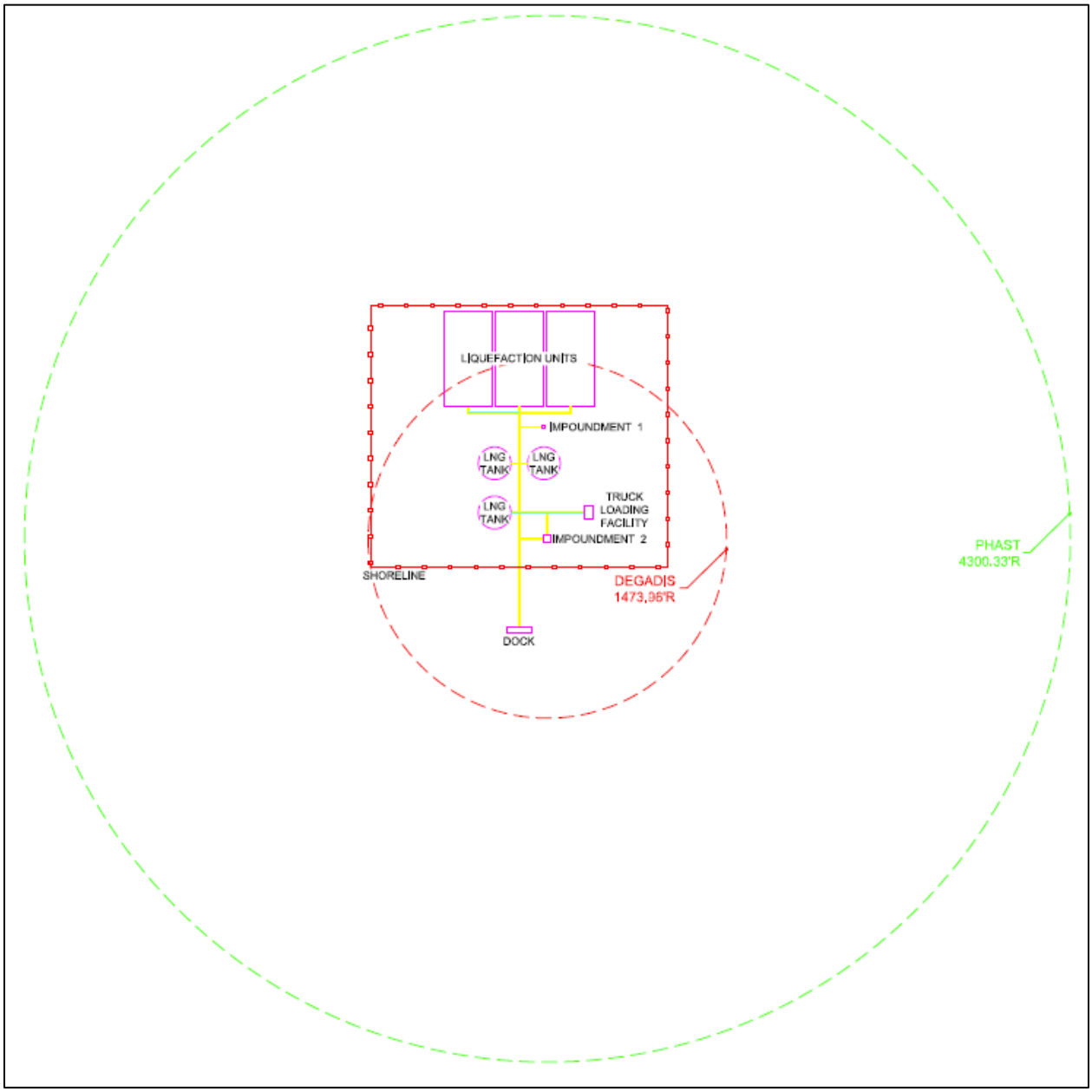

Figure 21.3-9: Marine Loading Line at Storage Tank (1 m/s, 0.01m)

Results Discussion:

The results for the rundown impoundment (impoundment #1) have the FLACS (without geometry) and DEGADIS models providing generally comparable results and the Phast model providing vapor dispersion predictions greater than the FLACS and DEGADIS model.

The FLACS model can take into account the depth of the impoundment, which can provide additional vapor holdup. The Phast model does not account for the depth of the impoundment, and therefore the FLACS results will be more representative. Therefore, the results are as expected.

The results for the marine loading impoundment (impoundment #2) have the FLACS (without geometry) providing the shortest distance followed by DEGADIS (as a factor of 3 greater than FLACS) and the Phast model (as a factor of 3 greater than DEGADIS) providing the furthest predicted vapor dispersion distances.

For Phast and FLACS, the properties of regular concrete were used for the impoundment modeling. Use of insulating concrete and its properties would reduce the vapor dispersion distances.

The majority of the releases stay within the plant property line for at least 1 model. The releases that extend beyond the facility property line can be mitigated with basic design optimizations.

All impoundment scenarios have smaller vapor dispersion exclusion zones compared to the jetting and flashing scenarios due to the high pressure release associated with jetting and flashing mechanism described in section 6 of this Report.

21.4 Overall Exclusion Zone

The overall exclusion zone for the facility is best represented by the FLACS model as that model can account for facility specifics, including; spill containment systems, process equipment, LNG tanks, piperacks, terrain and other facility geometric features. For the jetting and flashing, conveyance and impoundment modeling performed for the export facility, the overall exclusion zone is bounded by the jetting and flashing modeling as the extent of the jetting and flashing exclusion zones are further than the LNG conveyance and LNG impoundment exclusion zones. Jetting and flashing releases are modeled as a horizontal release directed towards the nearest property line therefore have high initial momentum towards the property line. This momentum and release orientation results in the jetting and flashing releases traveling further than the LNG conveyance or LNG impoundment vapor dispersion releases.

For the rundown line, it is unlikely that with layout optimization and basic mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The 1/3 diameter spill (5.3 inch hole) of the rundown line results in a very large spill which may be problematic, even for larger export facilities. This will require mitigation to maintain this spill within a property line.

For the rundown header, it is unlikely that with layout optimization and basic mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The 1/3 diameter spill (9.3 inch hole) of the rundown header results in a very large spill which may be problematic, even for larger export facilities. This will require mitigation to maintain this spill within a property line.

For the marine loading line, it is unlikely that with layout optimization and basic mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The 1/3 diameter spill (12 inch hole) of the marine loading line results in a very large spill which may be problematic, even for larger export facilities. This will require mitigation to maintain this spill within a property line.

For the truck loading line, it is likely that with layout optimization and mitigation the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration.

Therefore, mitigation measures such as ESD and vapor fences will need to be considered to reduce the associated dispersion distances. Mitigation modeling is evaluated further in Section 28 of this Report.

The overall exclusion zone is illustrated in Figure 21.4 below:

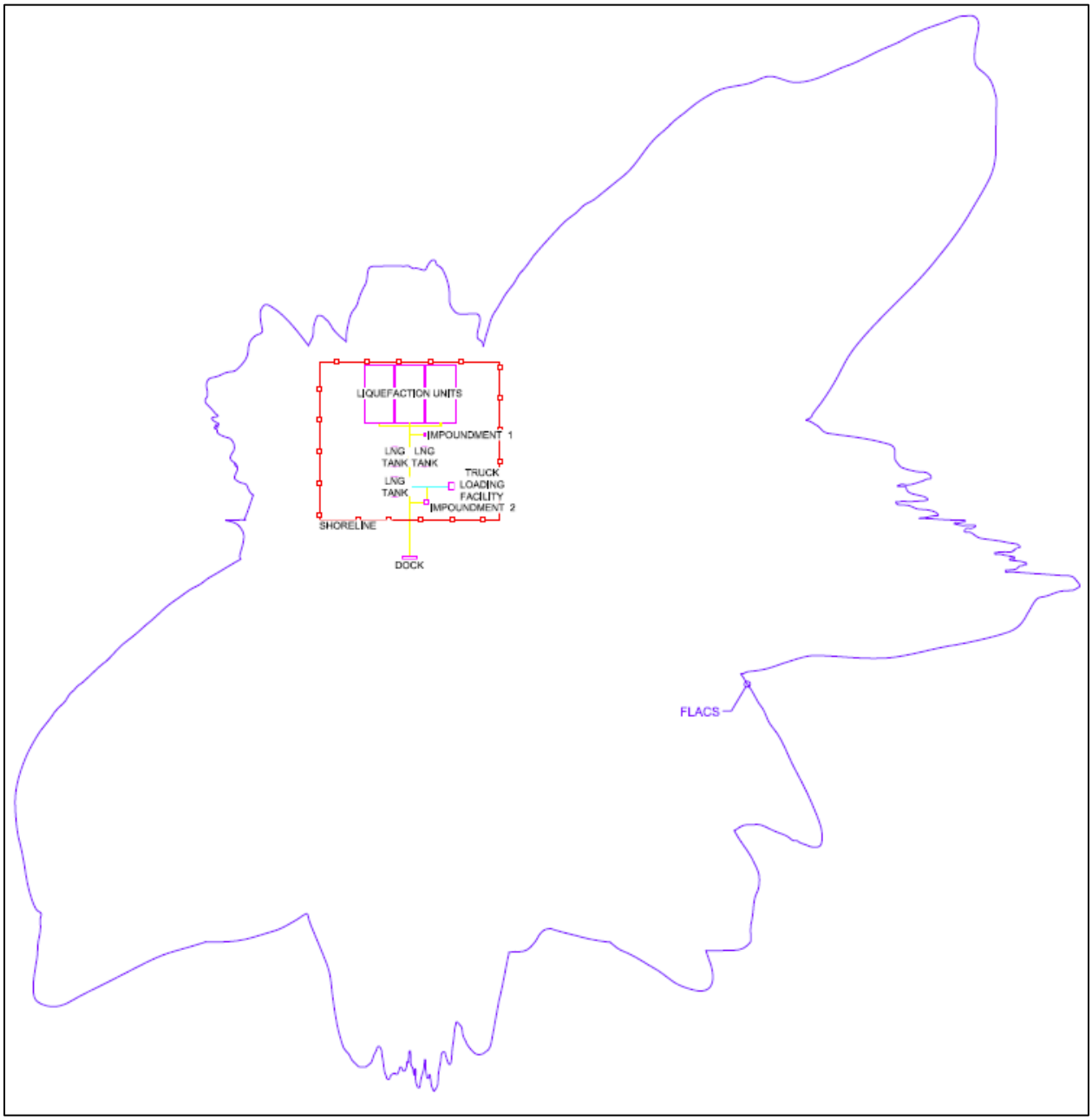

Figure 21.3: Overall Exclusion Zone

22 FUEL LOADING FACILITY VAPOR DISPERSION MODELING

22.1 Jetting and Flashing

The design spills used as the basis for jetting and flashing are detailed in Table 22.1-1.

Table 22.1-1: LNG Single Accidental Leakage Source

Spill Source (Scenario)	Failure Type	Line Size (inch)	Single Accidental Leakage Source (inch)
Rundown Line (F-1)	Pipe	2	Up to 2
Rundown Line (F-2)	Connection	1	1
Bunkering Line (F-3)	Pipe	4	Up to 4
Bunkering Line (F-4)	Connection	3	3
Bunkering Line (F-5)	Connection	2	2
Bunkering Line (F-6)	Connection	1	1

Operating conditions, such as temperature, pressure, flow rate and release elevation used in the analysis are presented in Table 22.1-2. Pump runout flow conditions associated with depressurization during a release scenario have been considered where applicable.

Table 22.1-2: LNG Process Conditions

Spill Source (Scenario)	Operating Temp (°F)	Operating Pressure (psig)	Operating Mass Flow Rate (lb/hr)	Release Elevation (ft)
Rundown Line (F-1)	-260	50	15,505	3
Rundown Line (F-2)	-260	50	15,505	3
Bunkering Line (F-3)	-260	40	80,757	3
Bunkering Line (F-4)	-260	40	80,757	3
Bunkering Line (F-5)	-260	40	80,757	3
Bunkering Line (F-6)	-260	40	80,757	3

In addition to location and flow rate considerations used to determine the design spills to be analyzed for jetting and flashing, the worst-case jetting and flashing scenarios (Bounding Scenarios) for the SALS detailed in Table 22.1-2 will result from a hole size that results in the greatest total vapor mass flow rate. When a pressurized leak occurs, the liquid jet will atomize and, depending on the operating conditions and release elevation, a portion of the jet may rainout and pool on the ground. Since the greatest total vapor mass flow rate associated with a single accidental leakage source may not occur at the largest hole size, PHAST was used to perform a sensitivity analysis on multiple hole sizes for pipe failures.

Table 22.1-3 presents the results of a sensitivity study for the scenarios to determine the Bounding Scenarios for pipe failures.

Table 22.1-3: Jetting and Flashing Sensitivity Study

Spill Source (Scenario)	Hole Size (in)	Equilibrium Pressure (psig)	Rainout %	Release Vapor Mass Flow Rate (lb/hr)	Pool Vapor Mass Flow Rate (lb/hr)	Total Vapor Mass Flow Rate (lb/hr)
Rundown Line (F-1)	0.62	50	0	15,875	0	15,875
Fuel Loading Line (F-3)	1.48	40	0	80,913	0	80,913

Based on the sensitivity study detailed in Table 22.1-3 and the design spills determined for all hole sizes, Table 22.1-4 presents the worst-case scenarios to be modeled.

Table 22.1-4: Worst Case Scenarios

Spill Scenario	Location/Spill Source:	Hole Size (in)
F-1	Rundown Line	0.62
F-3	Fuel Loading Line	1.48

Figure 22.1-1 illustrates the release location for the worst-case scenarios described in Table 22.1-4:

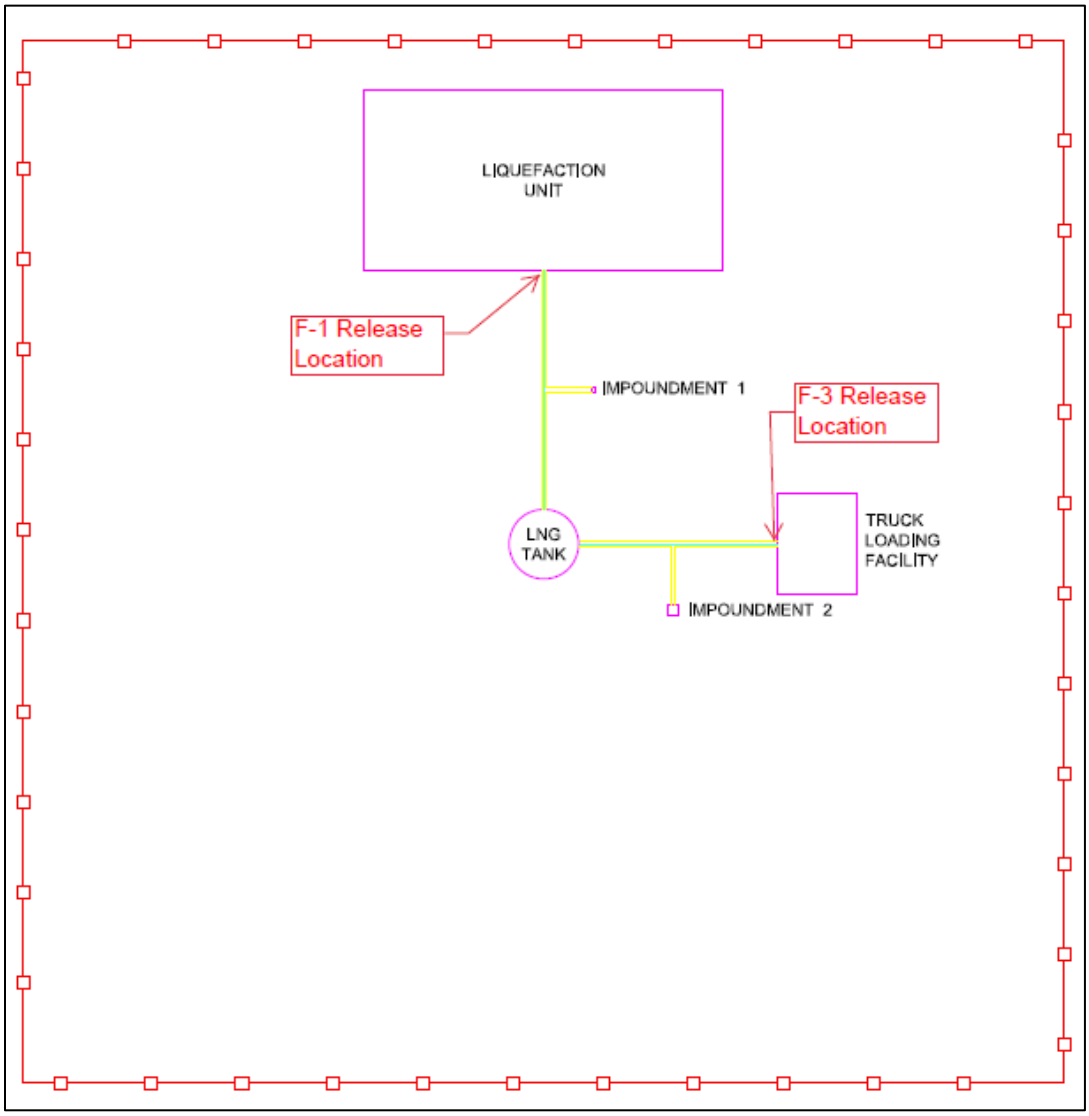

Figure 22.1-1: Jetting and Flashing Release Locations

The results of the modeling are included in Table 22.1-5.

Table 22.1-5: LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast Distance to ½ LFL (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)	FLACS Distance to ½ LFL (With Geometry) (ft)
F-1	2	0.03	345.12	223.10	Varies with direction
F-1	1	0.03	452.11	196.85	Varies with direction

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast Distance to ½ LFL (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)	FLACS Distance to ½ LFL (With Geometry) (ft)
F-3	2	0.03	705.59	410.10	Varies with direction
F-3	1	0.03	895.76	377.30	Varies with direction

The results of the jetting and flashing vapor dispersion modeling are illustrated in the following figures:

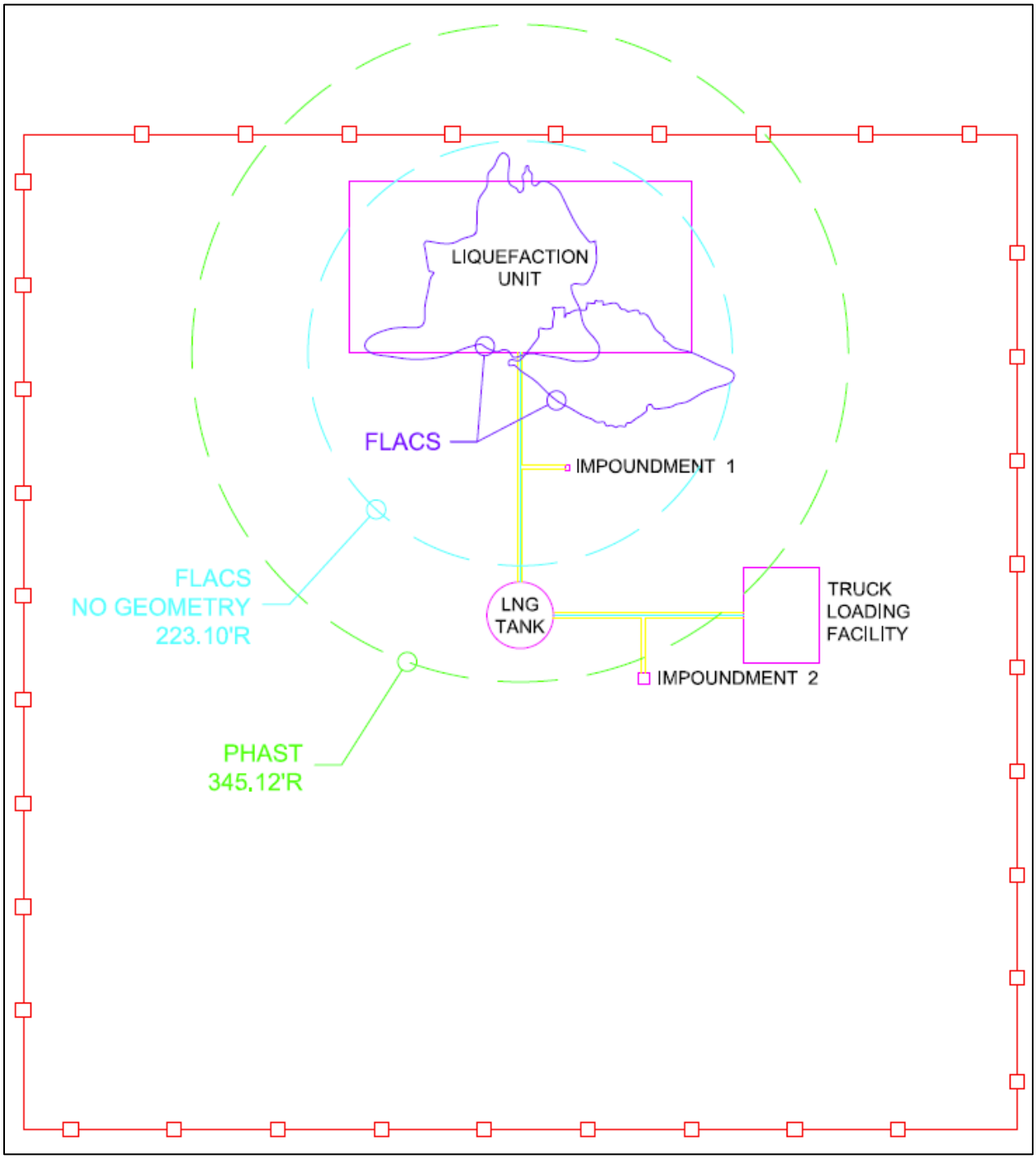

Figure 22.1-2: Rundown Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 22.1-2 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

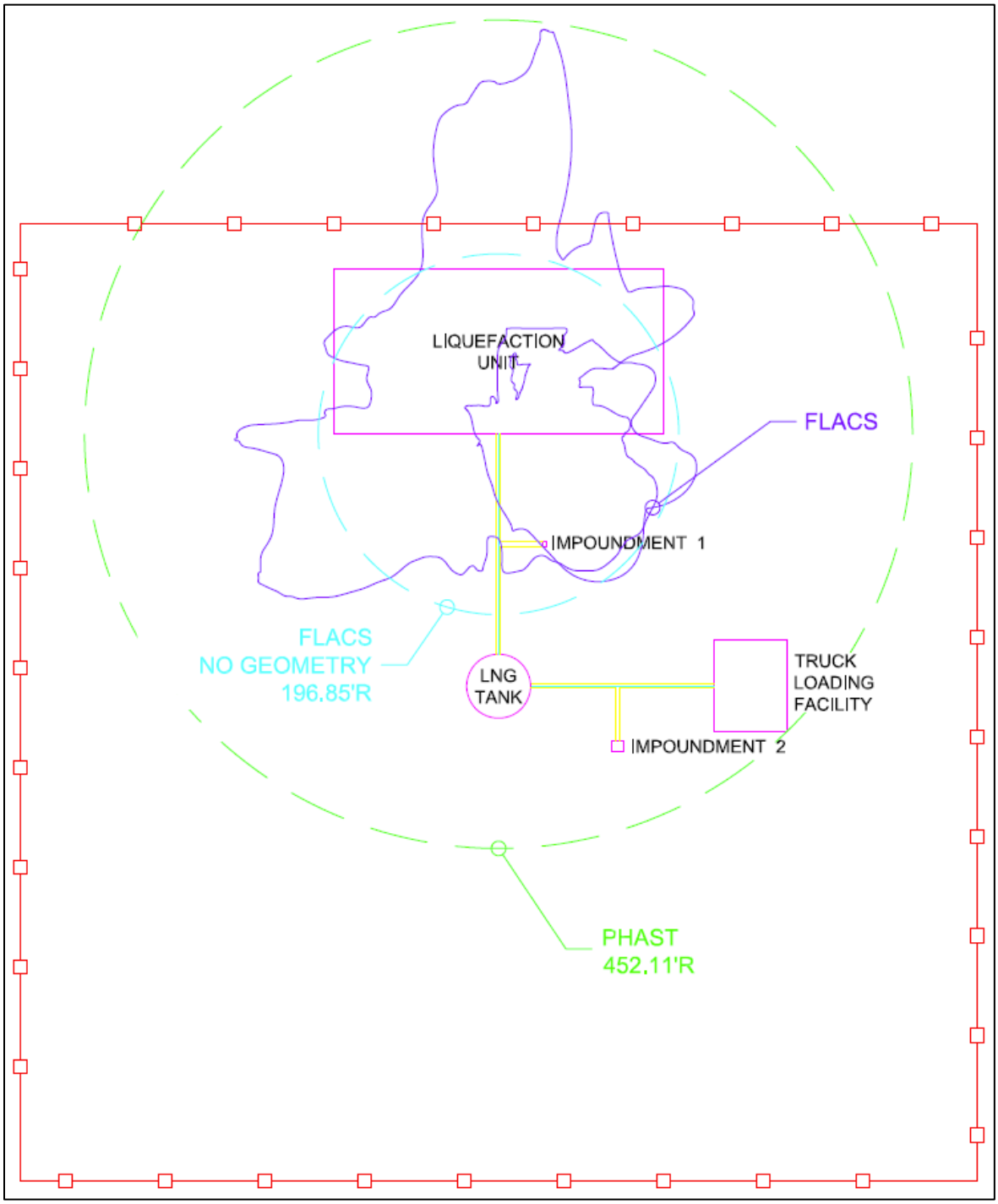

Figure 22.1-3: Rundown Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 22.1-3 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

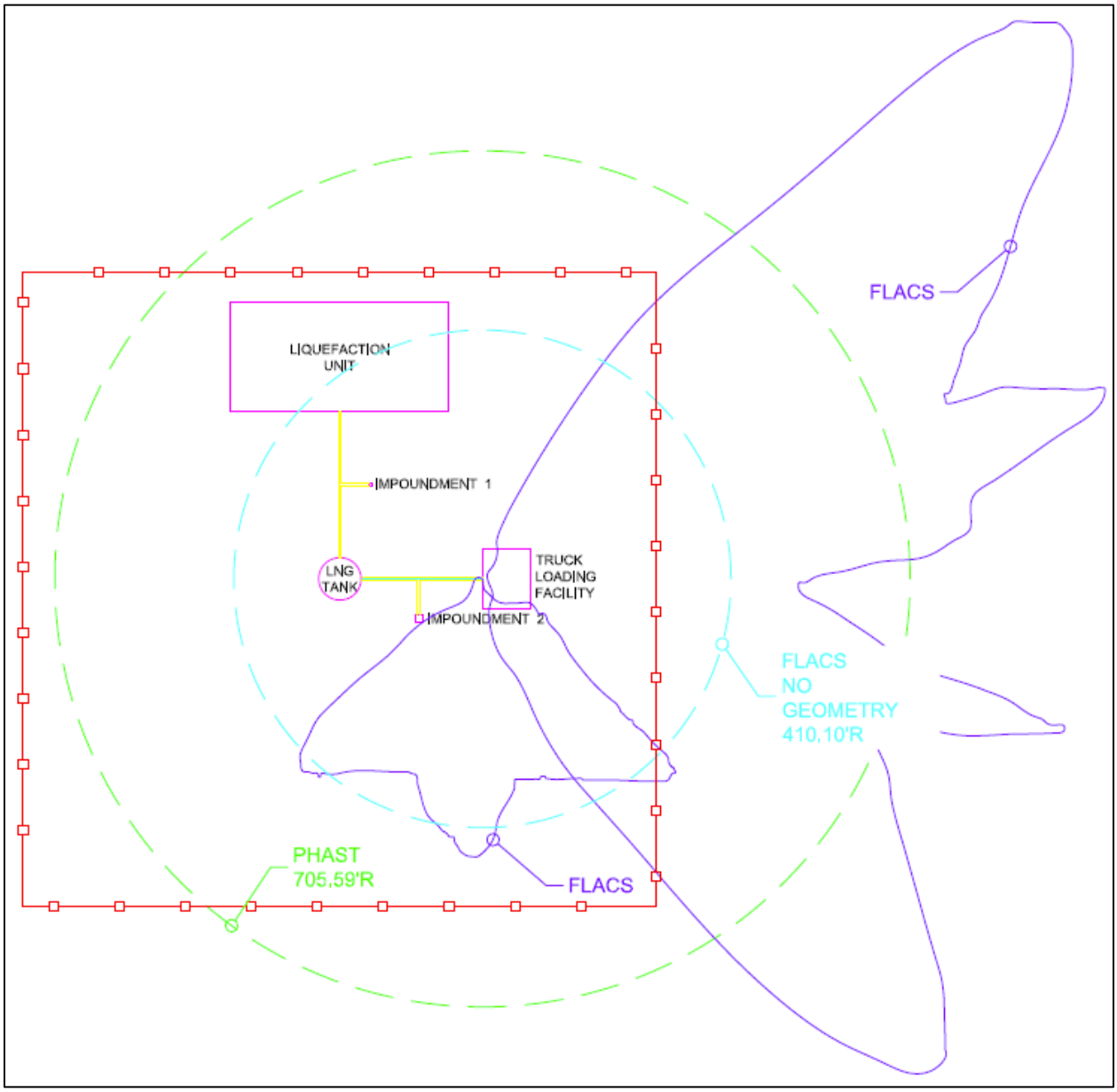

Figure 22.1-4: Fuel Loading Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 22.1-4 include (1) a release direction to the South with winds blowing to the South, Southwest and Southeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

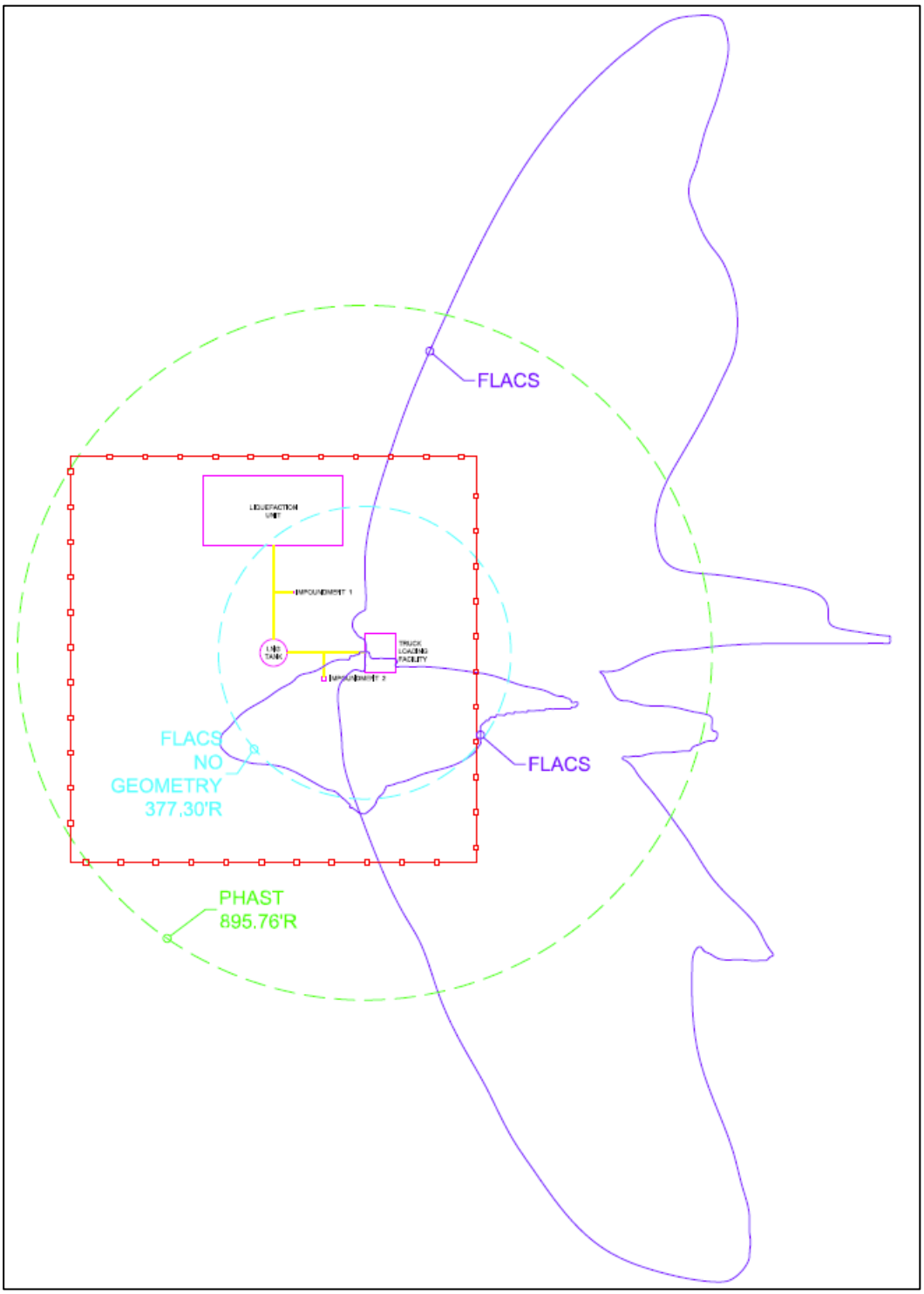

Figure 22.1-5: Fuel Loading Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 22.1-5 include (1) a release direction to the South with winds blowing to the South, Southwest and Southeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

Results Discussion:

For the rundown line, the results are generally comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 2 between the FLACS and Phast models.

For the fuel loading, the results are relatively comparable across the different models for releases to the South overall with variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 2-3 between the Phast and FLACS models. For the releases to the East, the FLACS dispersion gets held up by the obstacles, collects, and then gets dispersed by the wind. Therefore, the FLACS results are showing the furthest distances for releases to the East when including geometry.

22.2 LNG Conveyance

The design spills used as the basis for conveyance to impoundments are detailed in Table 22.2.

Table 22.2: LNG Conveyance Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10-Minute Spill Volume (ft^3)	Spill Containment Dimensions (ft x ft)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)
Rundown Line (F-1)	15,505	92.40	4 x 4	5 x 5 x 5	125
Fuel Loading Line (F-3)	80,757	481.2	4 x 4	12 x 12 x 10	2,450

Figure 22.2-1 illustrates the release location for the worst-case scenarios described in Table 22.2:

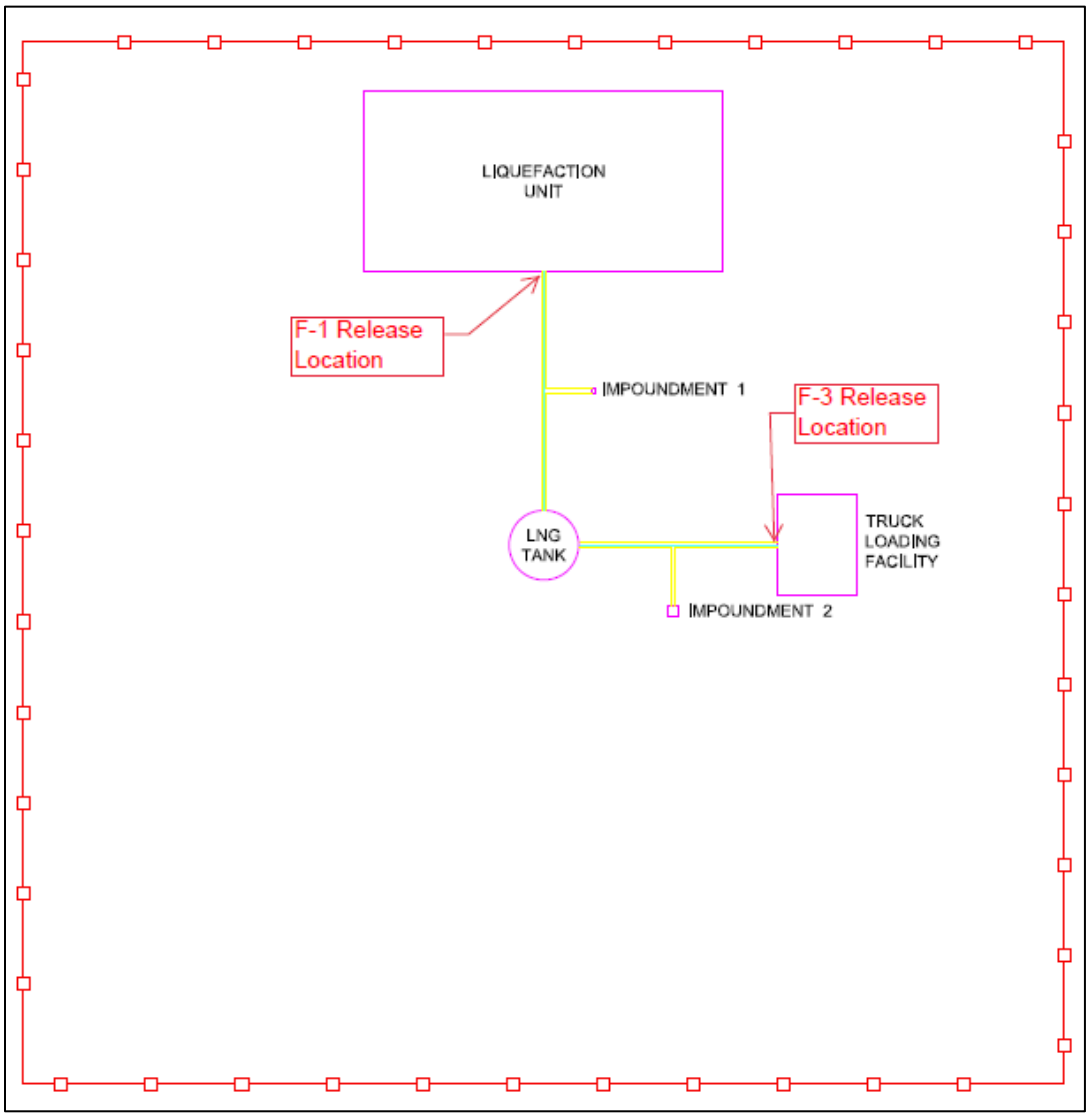

Figure 22.2-1: Conveyance Release Locations

All FLACS releases for LNG conveyance are for a release from the spill location as shown in Figure 22.2-1 into the spill containment system flowing towards the impoundment. The spill direction into the spill containment system is towards the impoundment. The results are presented in combined figures for winds blowing in the North, South, East, and West directions.

The results of the LNG conveyance to impoundment vapor dispersion modeling are illustrated in the following figures:

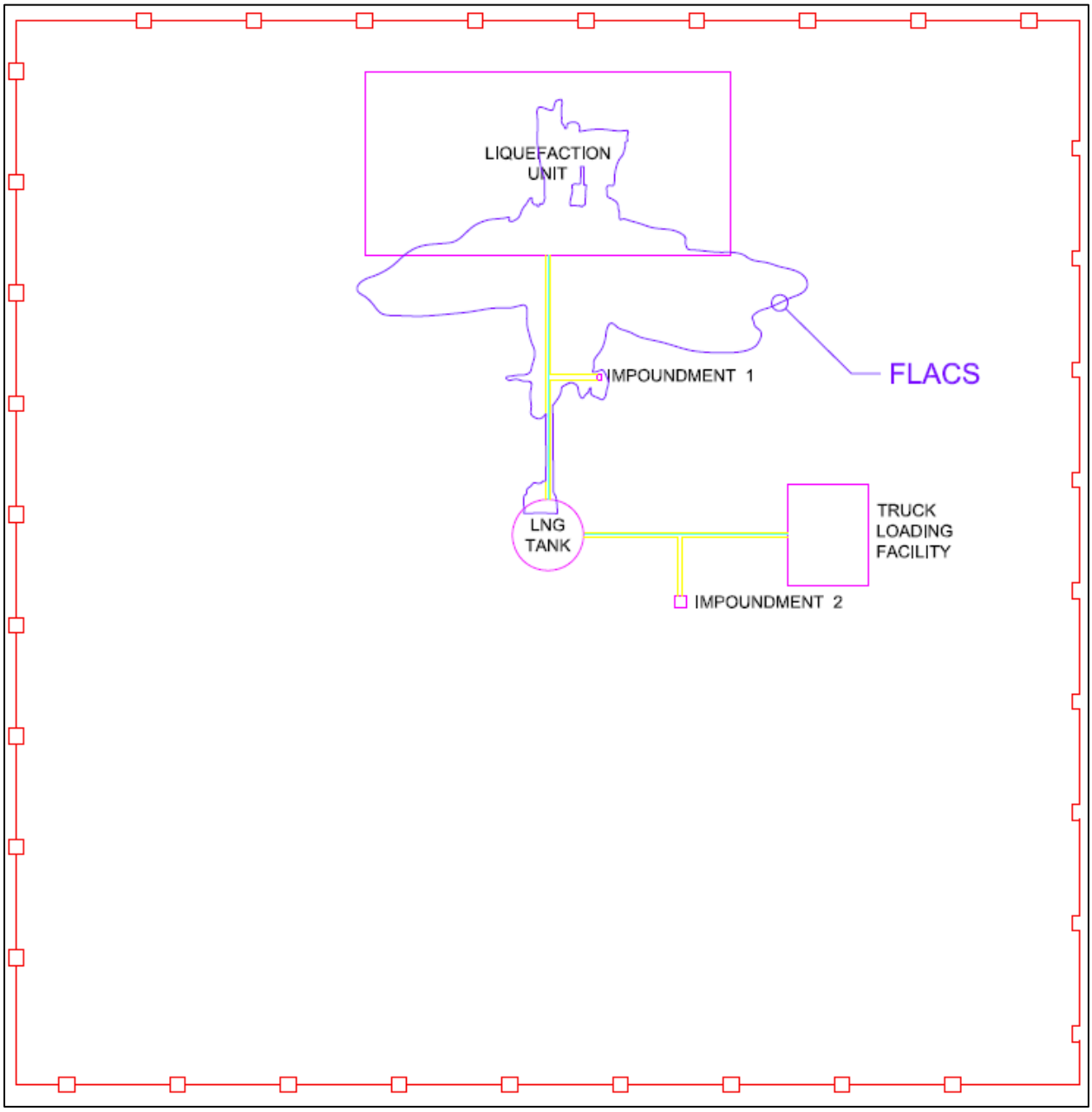

Figure 22.2-2: Rundown Line (2 m/s, 0.03m)

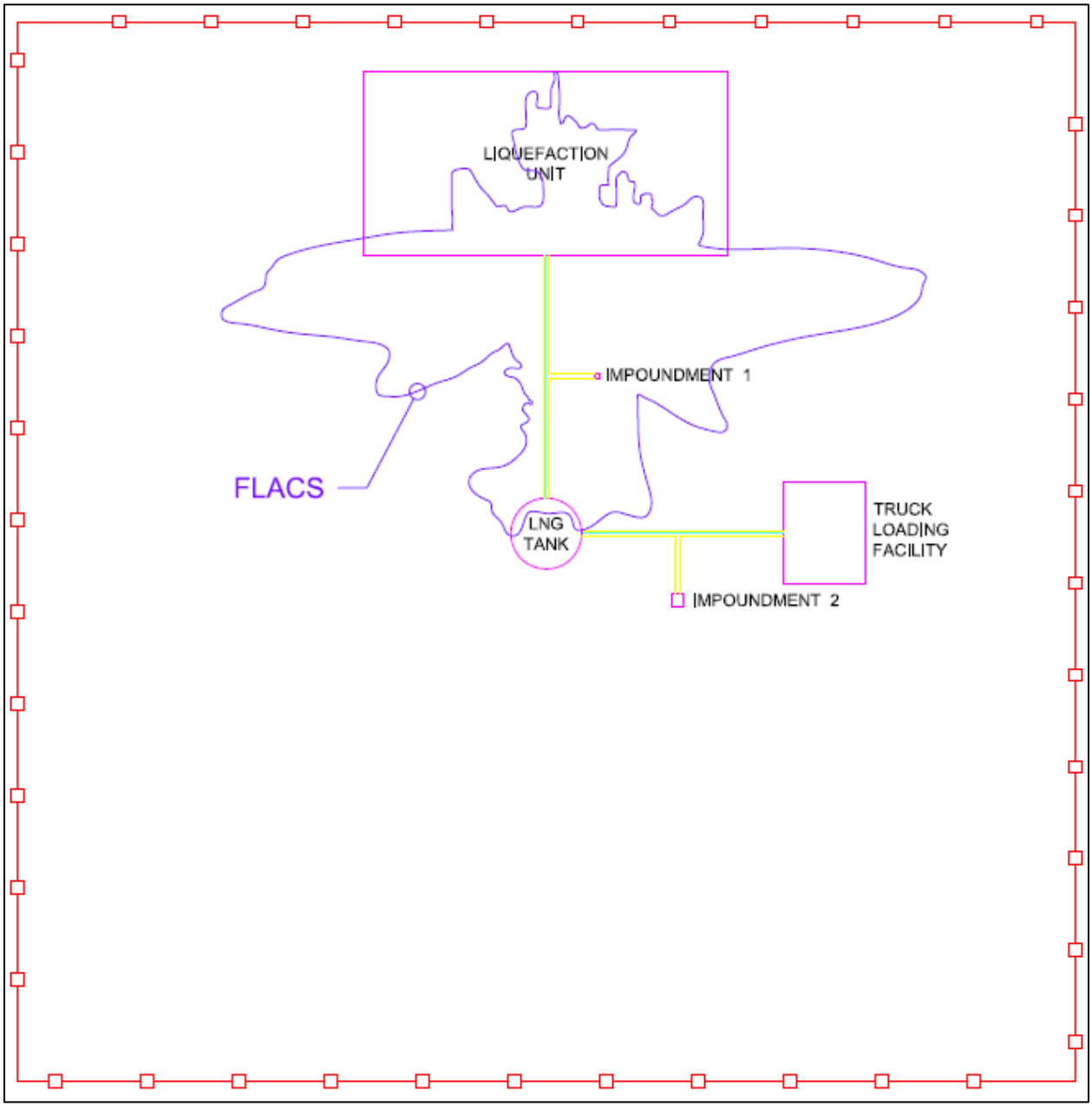

Figure 22.2-3: Rundown Line (1 m/s, 0.03m)

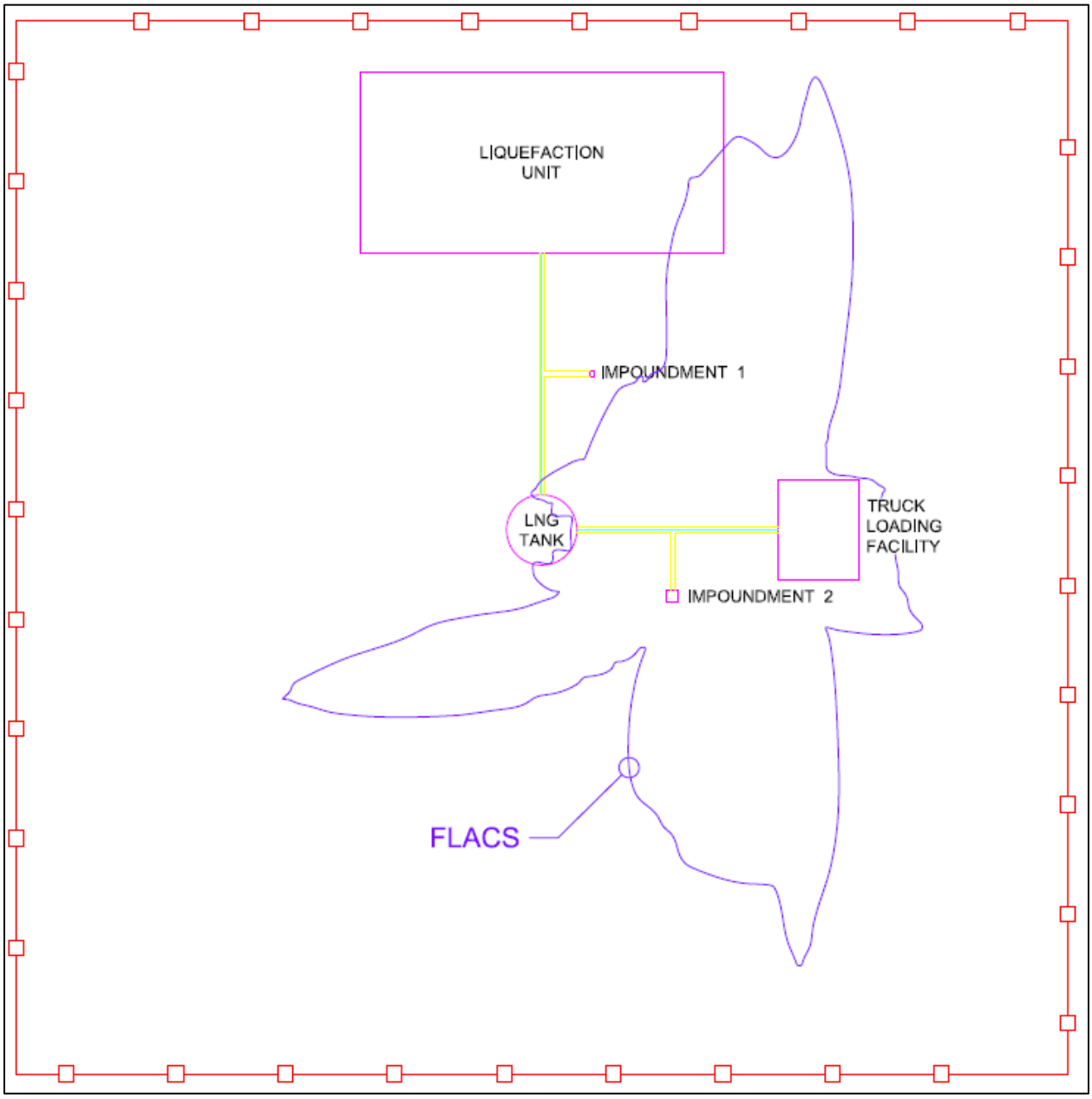

Figure 22.2-4: Fuel Loading Line (2 m/s, 0.03m)

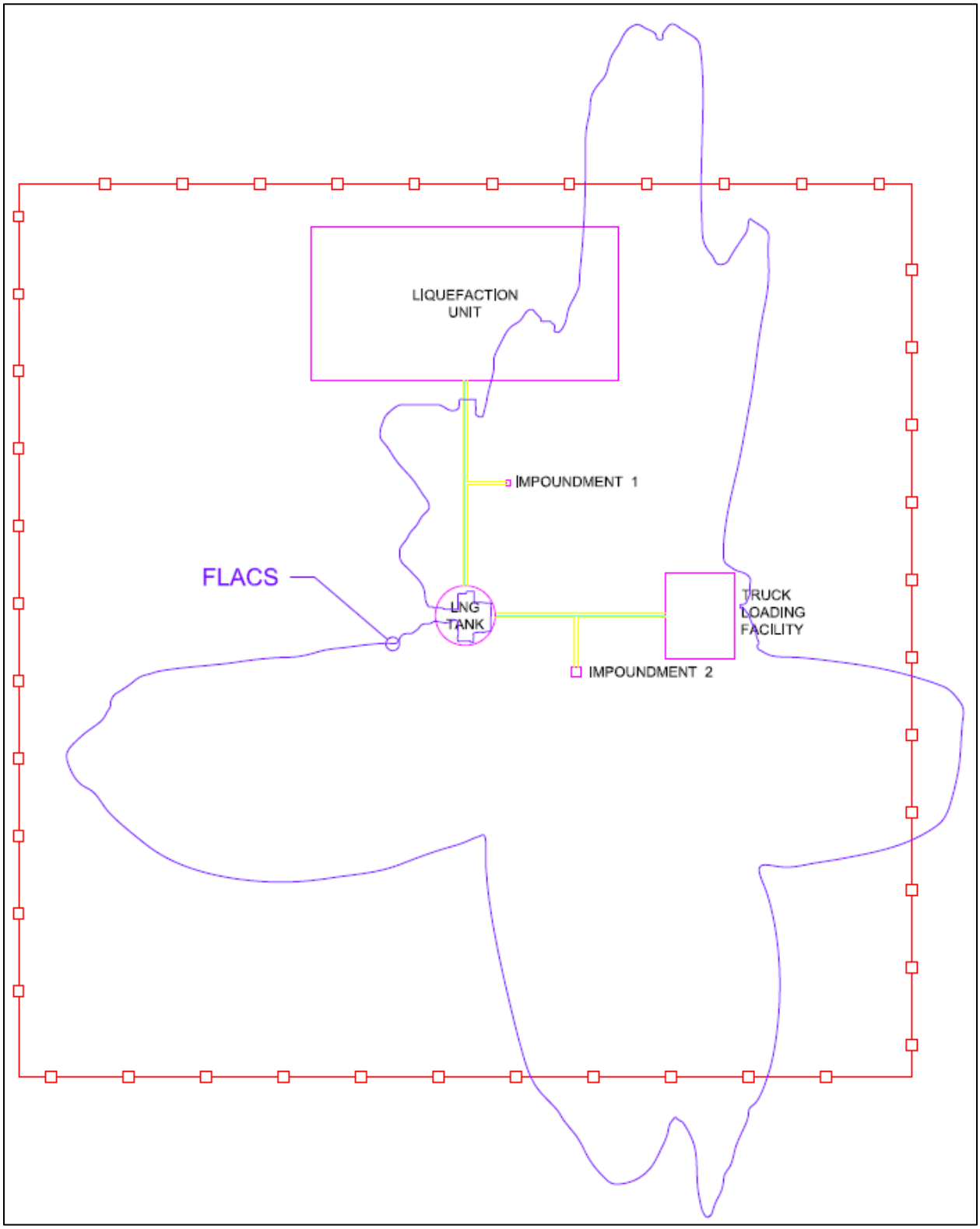

Figure 22.2-5: Fuel Loading Line (1 m/s, 0.03m)

Results Discussion:

The FLACS results illustrated in each figure for the different wind speed and surface roughness values are for a single release into the spill containment system which flows into the impoundment. The results presented are combined results for winds blowing in the North, South, East and West directions.

The majority of the releases stay within the plant property line. The releases that extend beyond the facility property line can be mitigated with basic design optimizations.

All conveyance scenarios have significantly smaller vapor dispersion exclusion zones compared to the jetting and flashing exclusion zones.

22.3 LNG Impoundments

The design spills used as the basis for LNG spills into impoundments are detailed in Table 22.3-1.

Table 22.3-1: LNG Impoundments Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10-Minute Spill Volume (ft^3)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)	Impoundment #
Rundown Line (F-1)	15,505	92.29	5 x 5 x 4	100	1
LNG Truck	N/A	1336.81	12 x 12 x 10	1,440	2

Figure 22.3-1 illustrates the release location for the worst-case scenarios described in Table 22.3-1:

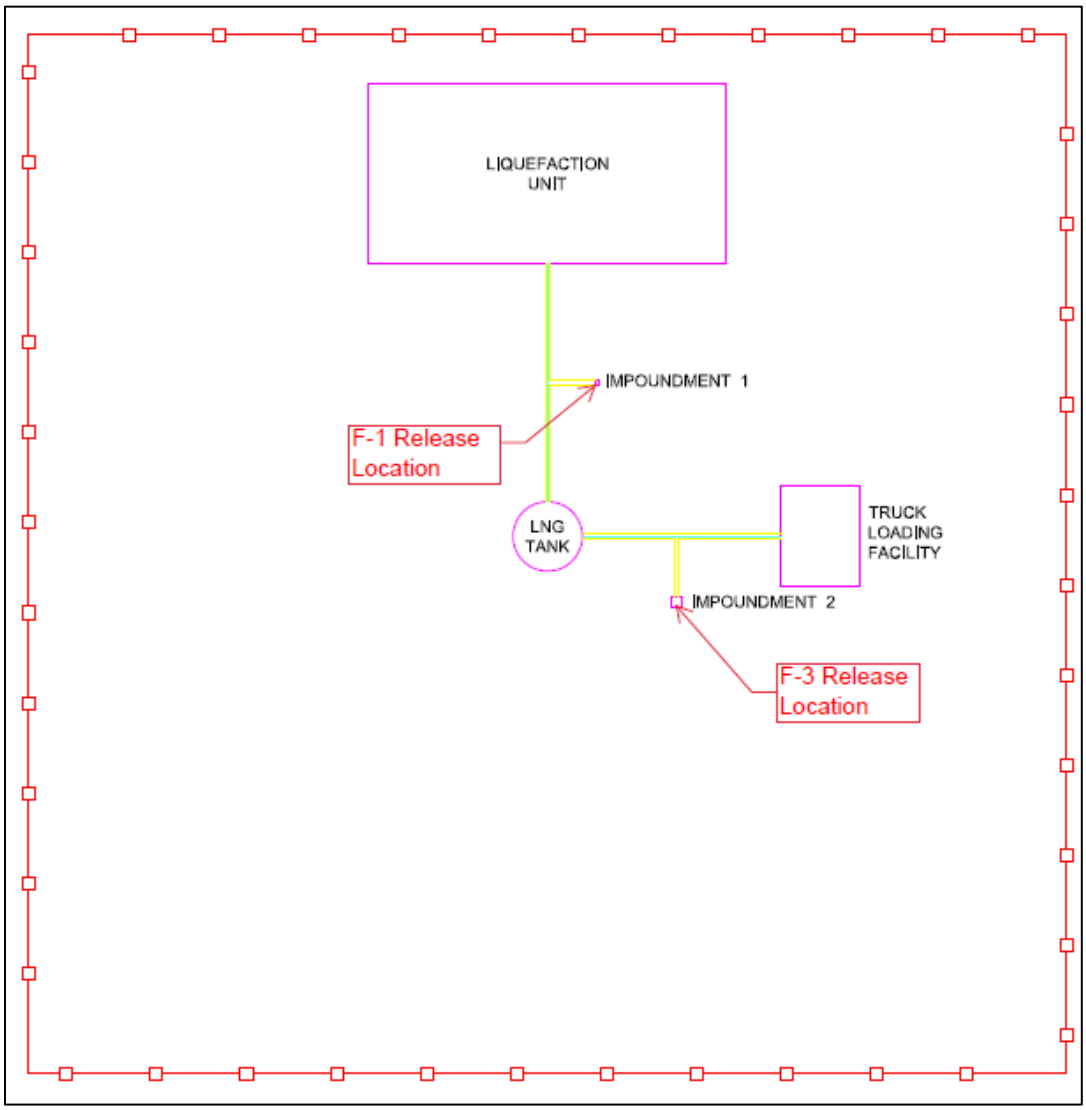

Figure 22.3-1: Impoundment Release Locations

The results of the LNG impoundment vapor dispersion modeling are detailed in Table 22.3-2.

Table 22.3-2: LNG Impoundments Vapor Dispersion Results

Spill Source (Scenario)	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast ½ LFL Distance (ft)	DEGADIS ½ LFL Distance (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)
Rundown Line (F-1)	2	0.03	241.35	96.54	36.09
Rundown Line (F-1)	1	0.03	331.54	89.24	32.81

Spill Source (Scenario)	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast ½ LFL Distance (ft)	DEGADIS ½ LFL Distance (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)
Fuel Loading Line (F-3)	2	0.03	300.07	104.26	68.90
Fuel Loading Line (F-3)	1	0.03	393.76	117.02	88.58

The results of the LNG impoundment vapor dispersion modeling are illustrated in the following figures:

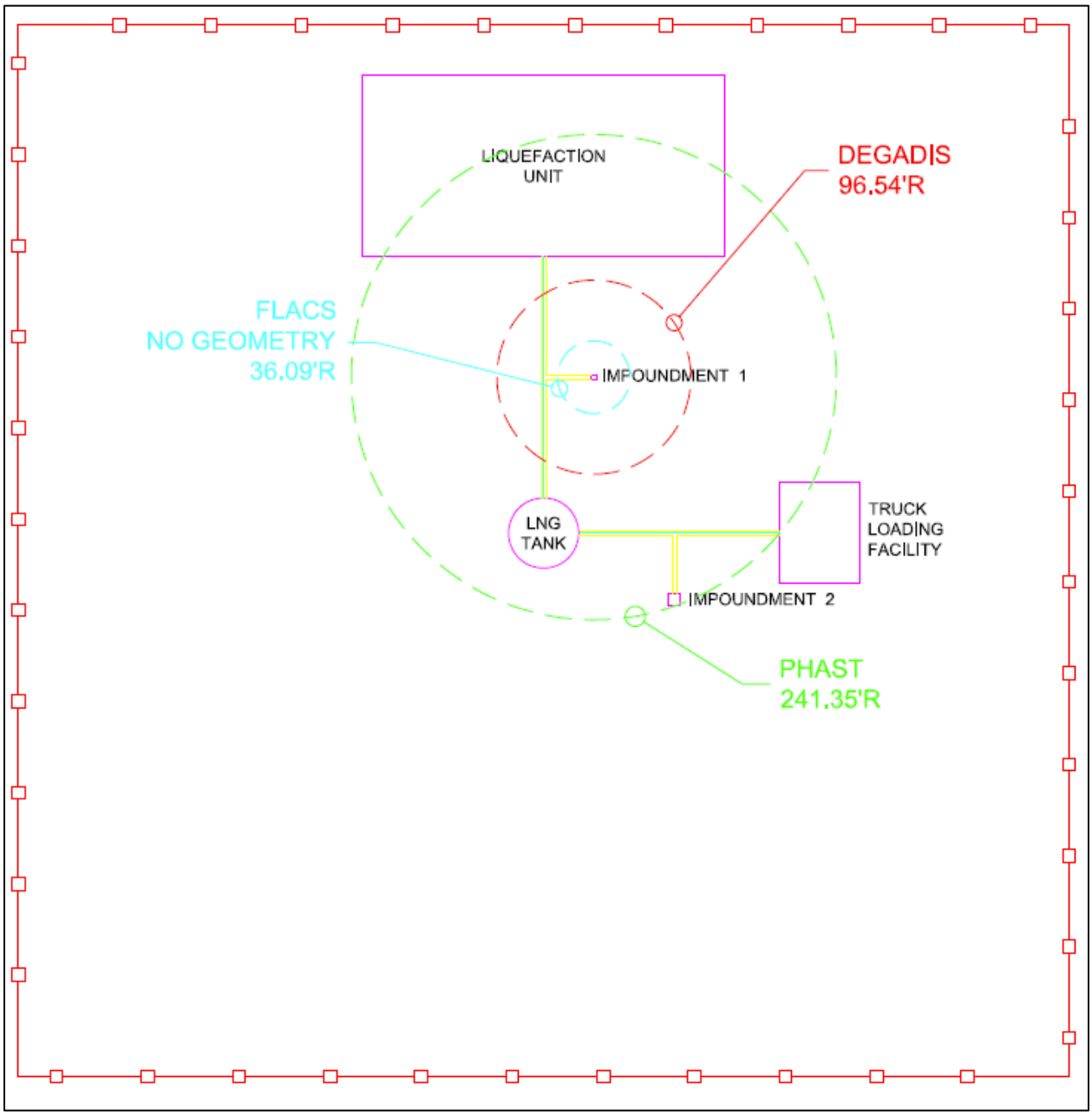

Figure 22.3-2: Rundown Line (2 m/s, 0.03m)

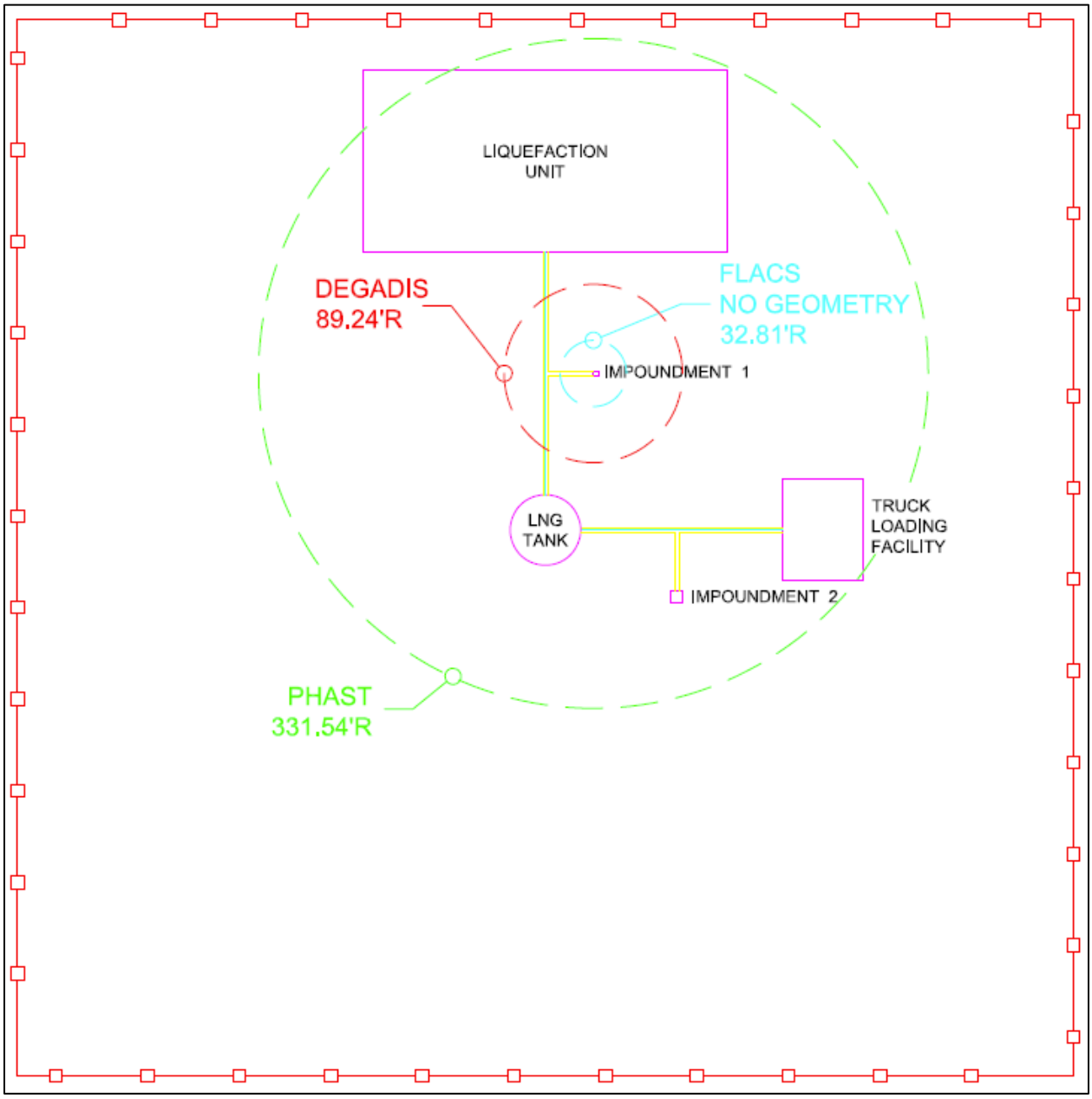

Figure 22.3-3: Rundown Line (1 m/s, 0.03m)

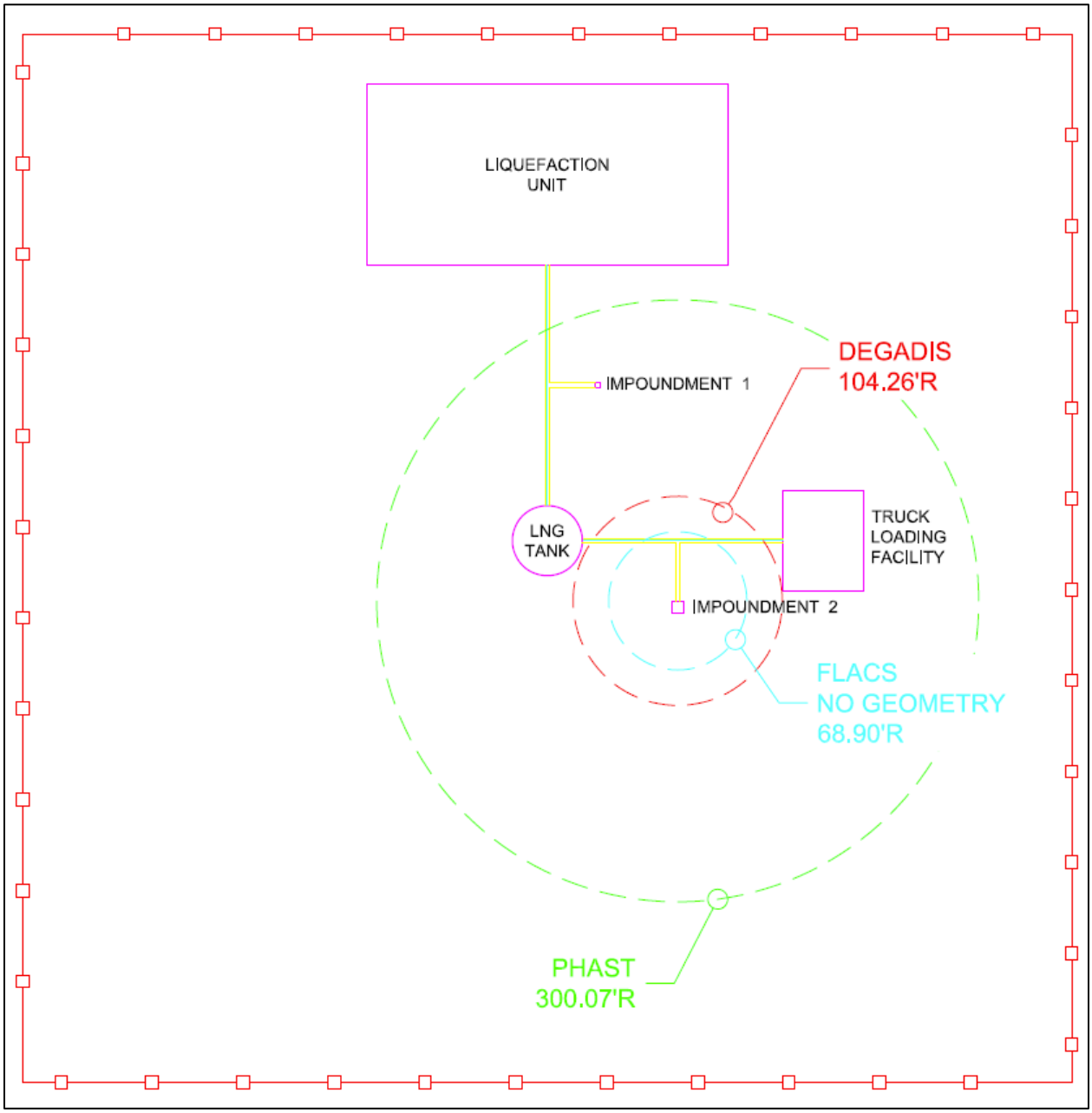

Figure 22.3-4: Fuel Loading Line (2 m/s, 0.03m)

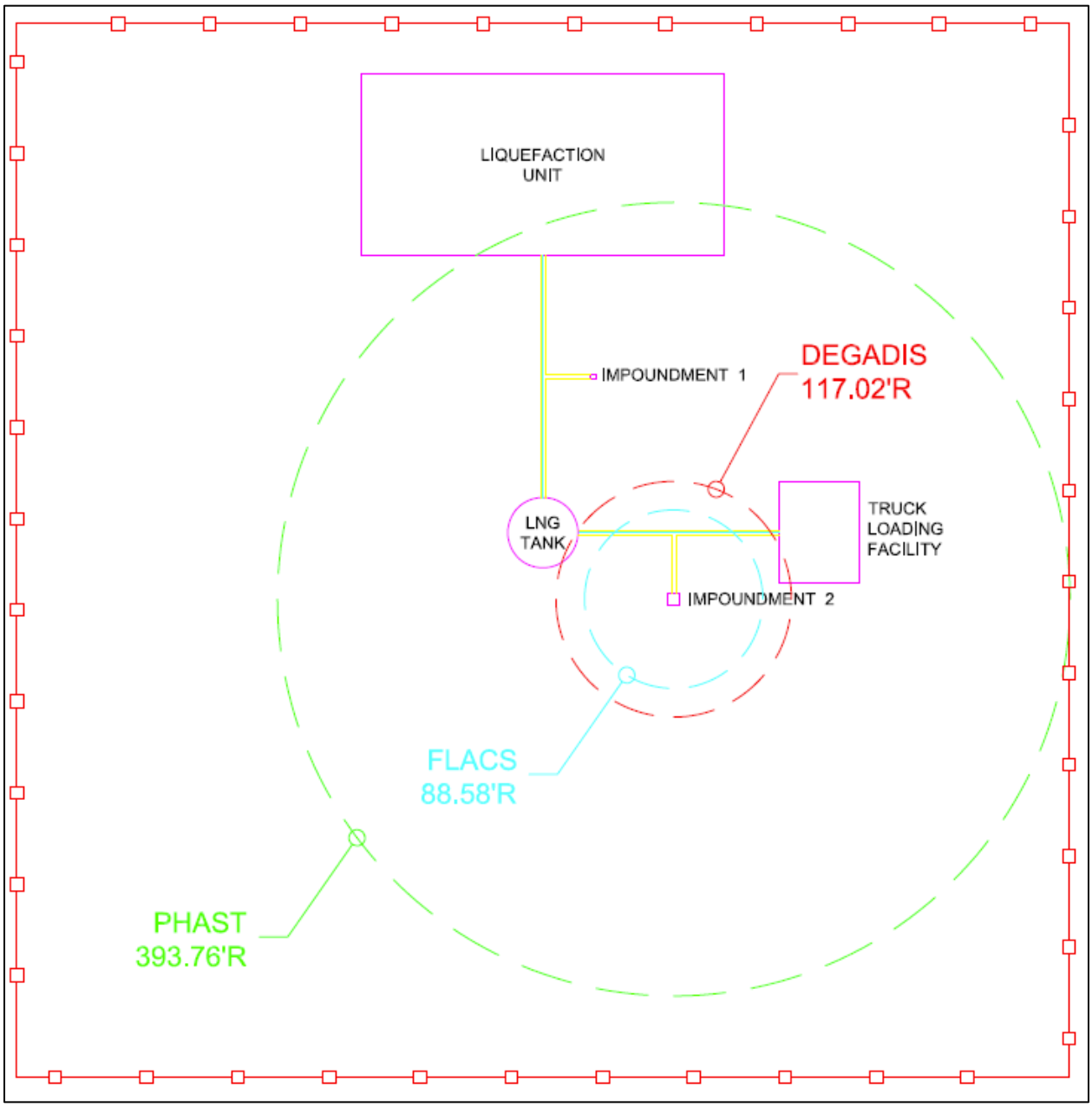

Figure 22.3-5: Fuel Loading Line (1 m/s, 0.03m)

Results Discussion:

The results for both impoundments have the FLACS (without geometry) and DEGADIS models providing generally comparable results and the Phast model providing vapor dispersion predictions greater than the FLACS and DEGADIS model. The results are within a factor of 2-3 between the FLACS and DEGADIS models and between a factor of 2-3 between the DEGADIS and Phast models.

The FLACS model can take into account the depth of the impoundment, which can provide additional vapor holdup. The Phast model does not account for the depth of the impoundment, and therefore the FLACS results will be more representative. Therefore, the results are as expected.

For Phast and FLACS, the properties of regular concrete were used for the impoundment modeling. Use of insulating concrete and its properties would reduce the vapor dispersion distances.

22.4 Overall Exclusion Zone

The overall exclusion zone for the facility is best represented by the FLACS model as that model can account for facility specifics, including; spill containment systems, process equipment, LNG tanks, piperacks, terrain and other facility geometric features. For the jetting and flashing, conveyance, and impoundment modeling performed for the fuel loading facility, the overall exclusion zone is bounded by the jetting and flashing modeling as the extent of the jetting and flashing exclusion zones are further than the LNG conveyance and LNG impoundment exclusion zones. Jetting and flashing releases are modeled as a horizontal release directed towards the nearest property line therefore have high initial momentum towards the property line. This momentum and release orientation results in the jetting and flashing releases traveling further than the LNG conveyance or LNG impoundment vapor dispersion releases.

For the rundown line, it is likely that with layout optimization and mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration.

For the fuel loading line, it is unlikely that with layout optimization and basic mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The failure of the fuel loading line results in a very large spill which may be problematic for smaller fuel loading facilities. This will require mitigation to maintain this spill within a property line.

Therefore, mitigation measures such as ESD and vapor fences will need to be considered to reduce the associated dispersion distances. Mitigation modeling is evaluated further in Section 29 of this Report.

The overall exclusion zone is illustrated in Figure 22.3 below:

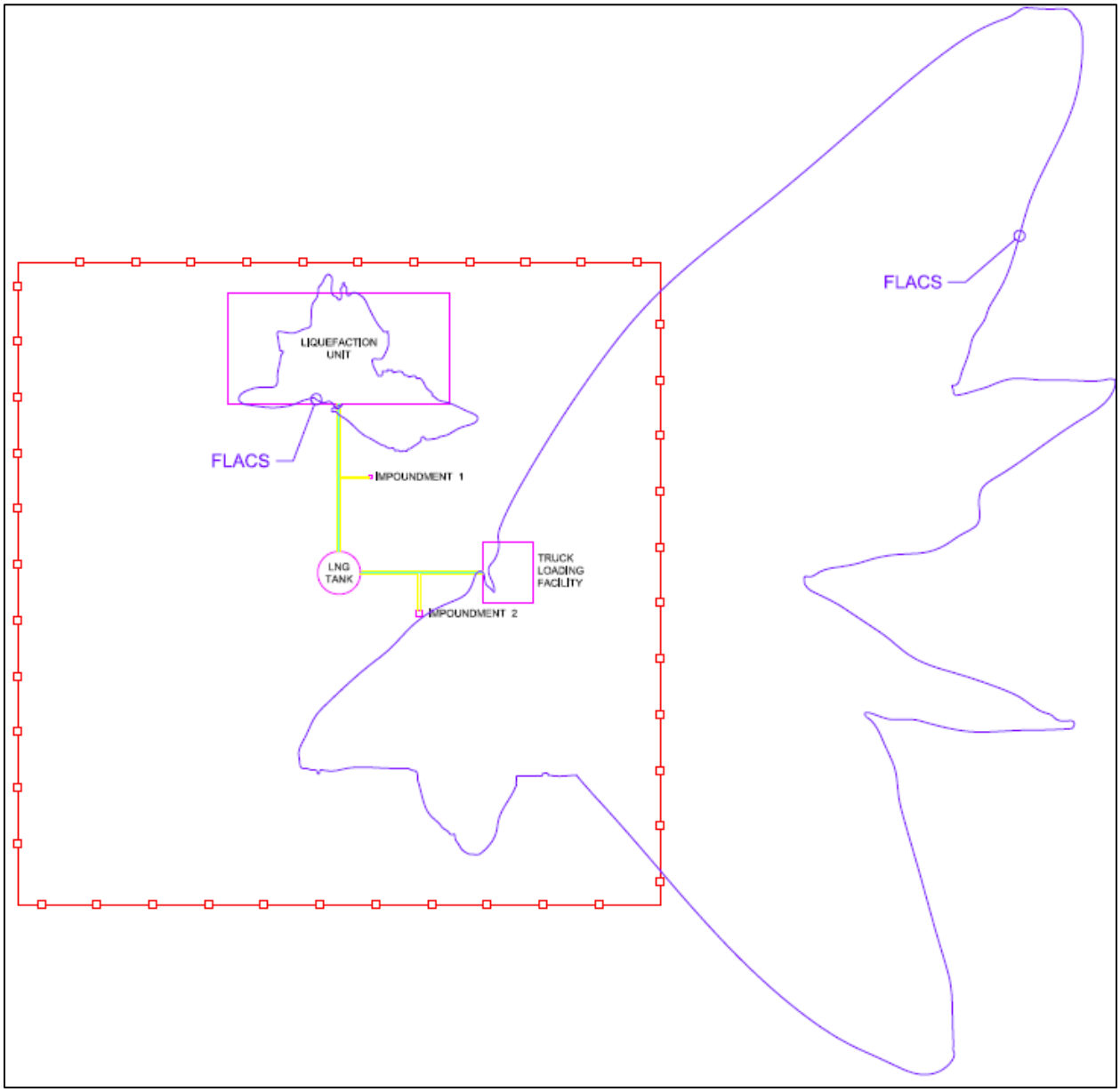

Figure 22.3: Overall Exclusion Zone

23 PEAKSHAVER FACILITY VAPOR DISPERSION MODELING

23.1 Jetting and Flashing

The design spills used as the basis for jetting and flashing are detailed in Table 23.1-1.

Table 23.1-1: LNG Single Accidental Leakage Source

Spill Source (Scenario)	Failure Type	Line Size (inch)	Single Accidental Leakage Source (inch)
Rundown Line (P-1)	Pipe	4	Up to 2
Rundown Line (P-2)	Connection	3	3
Rundown Line (P-3)	Connection	2	2
Rundown Line (P-4)	Connection	1	1
LP Sendout Line (P-5)	Pipe	10	Up to 10
LP Sendout Line (P-6)	Connection	4	4
LP Sendout Line (P-7)	Connection	3	3
LP Sendout Line (P-8)	Connection	2	2
LP Sendout Line (P-9)	Connection	1	1
HP Sendout Line (P-10)	Pipe	10	Up to 3.3
HP Sendout Line (P-11)	Connection	4	4
HP Sendout Line (P-12)	Connection	3	3
HP Sendout Line (P-13)	Connection	2	2
HP Sendout Line (P-14)	Connection	1	1
Truck Loading Line (P-15)	Pipe	4	Up to 4
Truck Loading Line (P-16)	Connection	3	3
Truck Loading Line (P-17)	Connection	2	2
Truck Loading Line (P-18)	Connection	1	1

Operating conditions, such as temperature, pressure, flow rate and release elevation used in the analysis are presented in Table 23.1-2. Pump runout flow conditions associated with depressurization during a release scenario have been considered where applicable.

Table 23.1-2: LNG Process Conditions

Spill Source (Scenario)	Operating Temp (°F)	Operating Pressure (psig)	Operating Mass Flow Rate (lb/hr)	Release Elevation (ft)
Rundown Line (P-1)	-260	50	48,454	3
Rundown Line (P-2)	-260	50	48,454	3
Rundown Line (P-3)	-260	50	48,454	3
Rundown Line (P-4)	-260	50	48,454	3
LP Sendout Line (P-5)	-260	40	930,317	3
LP Sendout Line (P-6)	-260	40	930,317	3
LP Sendout Line (P-7)	-260	40	930,317	3

Spill Source (Scenario)	Operating Temp (°F)	Operating Pressure (psig)	Operating Mass Flow Rate (lb/hr)	Release Elevation (ft)
LP Sendout Line (P-8)	-260	40	930,317	3
LP Sendout Line (P-9)	-260	40	930,317	3
HP Sendout Line (P-10)	-260	800	930,317	3
HP Sendout Line (P-11)	-260	800	930,317	3
HP Sendout Line (P-12)	-260	800	930,317	3
HP Sendout Line (P-13)	-260	800	930,317	3
HP Sendout Line (P-14)	-260	800	930,317	3
Truck Loading Line (P-15)	-260	40	80,757	3
Truck Loading Line (P-16)	-260	40	80,757	3
Truck Loading Line (P-17)	-260	40	80,757	3
Truck Loading Line (P-18)	-260	40	80,757	3

In addition to location and flow rate considerations used to determine the design spills to be analyzed for jetting and flashing, the worst-case jetting and flashing scenarios (Bounding Scenarios) for the SALS detailed in Table 23.1-2 will result from a hole size that results in the greatest total vapor mass flow rate. When a pressurized leak occurs, the liquid jet will atomize and, depending on the operating conditions and release elevation, a portion of the jet may rainout and pool on the ground. Since the greatest total vapor mass flow rate associated with a single accidental leakage source may not occur at the largest hole size, PHAST was used to perform a sensitivity analysis on multiple hole sizes for pipe failures.

Table 23.1-3 presents the results of a sensitivity study for the scenarios to determine the Bounding Scenarios for pipe failures.

Table 23.1-3: Jetting and Flashing Sensitivity Study

Spill Source (Scenario)	Hole Size (in)	Equilibrium Pressure (psig)	Rainout %	Release Vapor Mass Flow Rate (lb/hr)	Pool Vapor Mass Flow Rate (lb/hr)	Total Vapor Mass Flow Rate (lb/hr)
Rundown Line (P-1)	1.09	50	0	49,068	0	49,068
LP Sendout Line (P-5)	5	40	55	421,600	424,200	845,800
HP Sendout Line (P-10)	3.3	214	0	930,453	0	930,453
Truck Loading Line (P-15)	1.48	40	0	80,913	0	80,913

Based on the sensitivity study detailed in Table 23.1-3 and the design spills determined for all hole sizes, Table 23.1-4 presents the worst-case scenarios to be modeled.

Table 23.1-4: Worst Case Scenarios

Spill Scenario	Location/Spill Source:	Hole Size (in)
P-1	Rundown Line	1.09
P-5	LP Sendout Line	5
P-10	HP Sendout Line	3.3
P-15	Truck Loading Line	1.48

Figure 23.1-1 illustrates the release location for the worst-case scenarios described in Table 23.1-4:

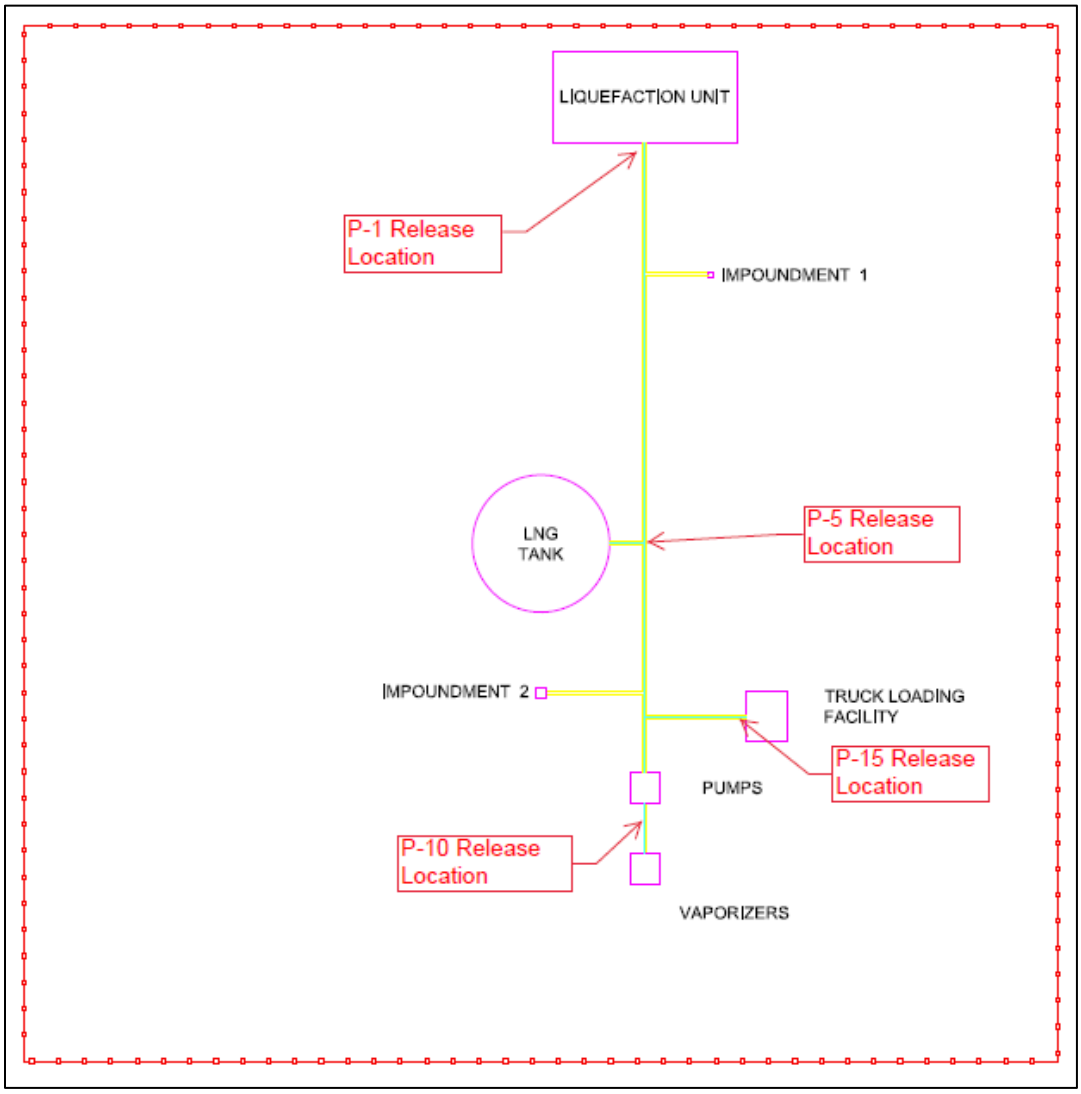

Figure 23.1-1: Jetting and Flashing Release Locations

The results of the modeling are included in Table 23.1-5.

Table 23.1-5: LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast Distance to ½ LFL (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)	FLACS Distance to ½ LFL (With Geometry) (ft)
P-1	2	0.03	562.65	328.08	Varies with direction
P-1	1	0.03	723.09	288.71	Varies with direction

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast Distance to ½ LFL (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)	FLACS Distance to ½ LFL (With Geometry) (ft)
P-5	2	0.03	1,929.05	3,937.01	Varies with direction
P-5	1	0.03	2,413.68	4,691.6	Varies with direction
P-10	2	0.03	2,639.99	951.44	Varies with direction
P-10	1	0.03	1,753.39	885.83	Varies with direction
P-15	2	0.03	687.93	951.44	Varies with direction
P-15	1	0.03	872.16	672.57	Varies with direction

The results of the jetting and flashing vapor dispersion modeling are illustrated in the following figures:

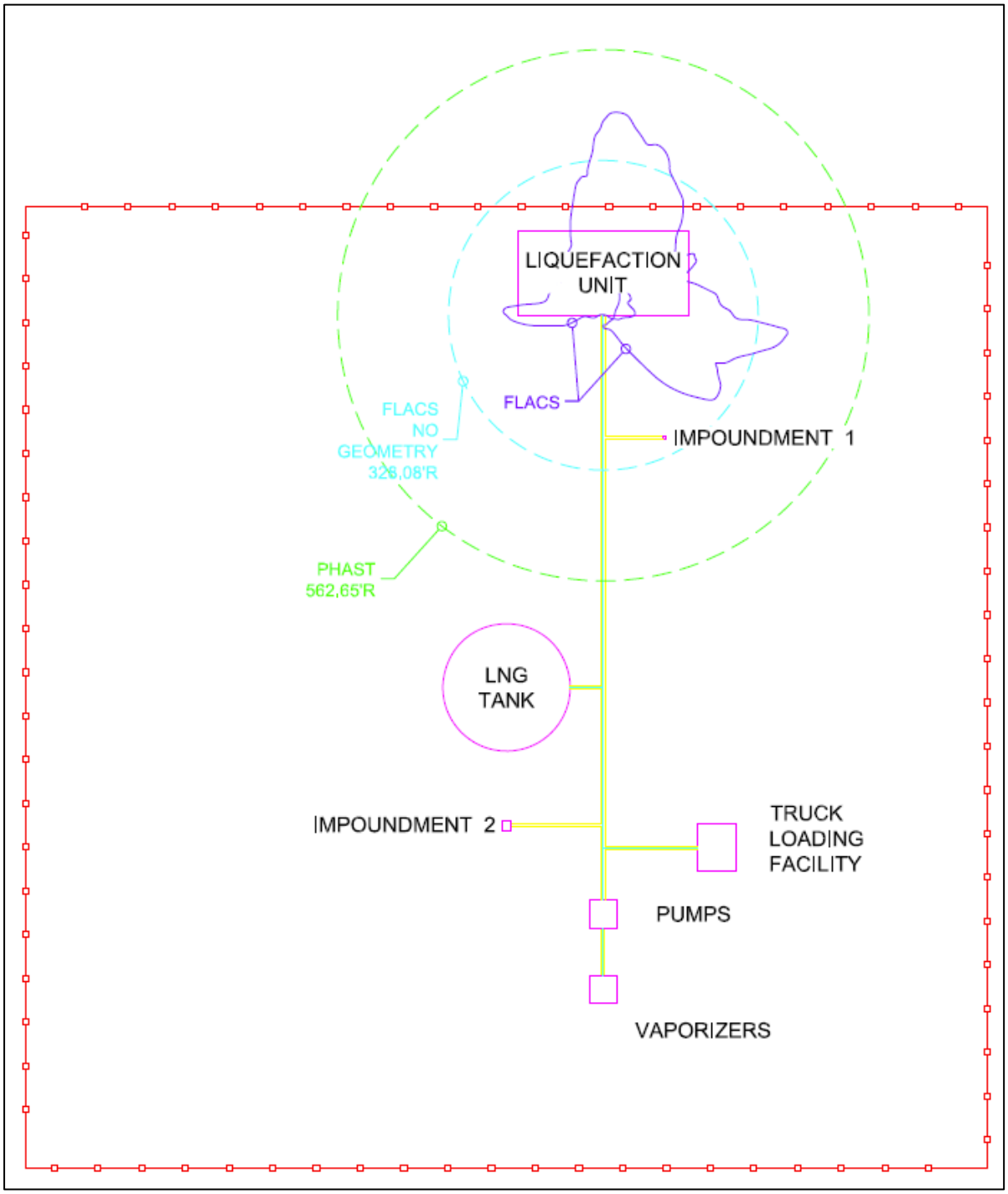

Figure 23.1-2: Rundown Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-2 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

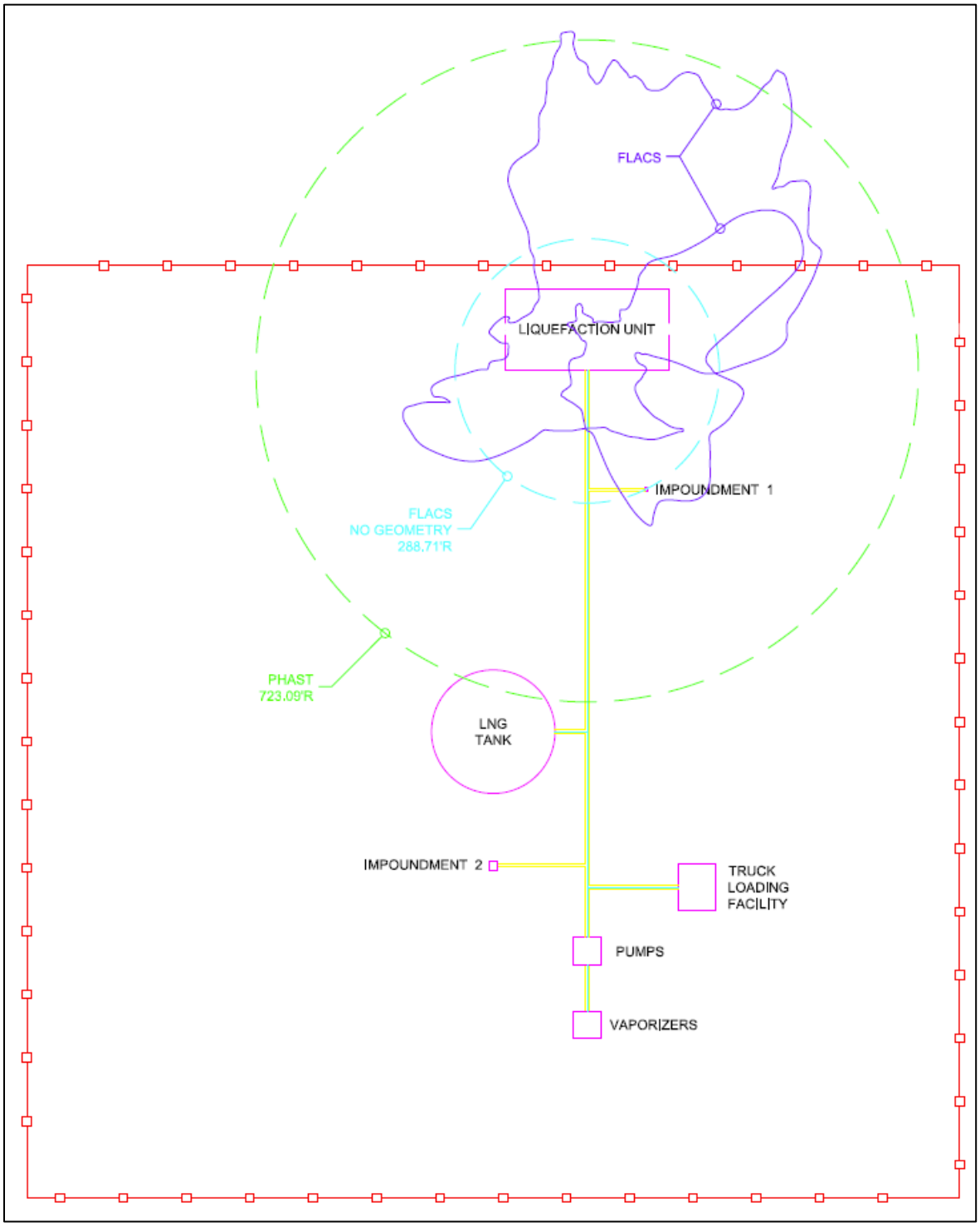

Figure 23.1-3: Rundown Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-3 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast and (2) a release direction to the East with winds blowing to the East, Northeast and Southeast.

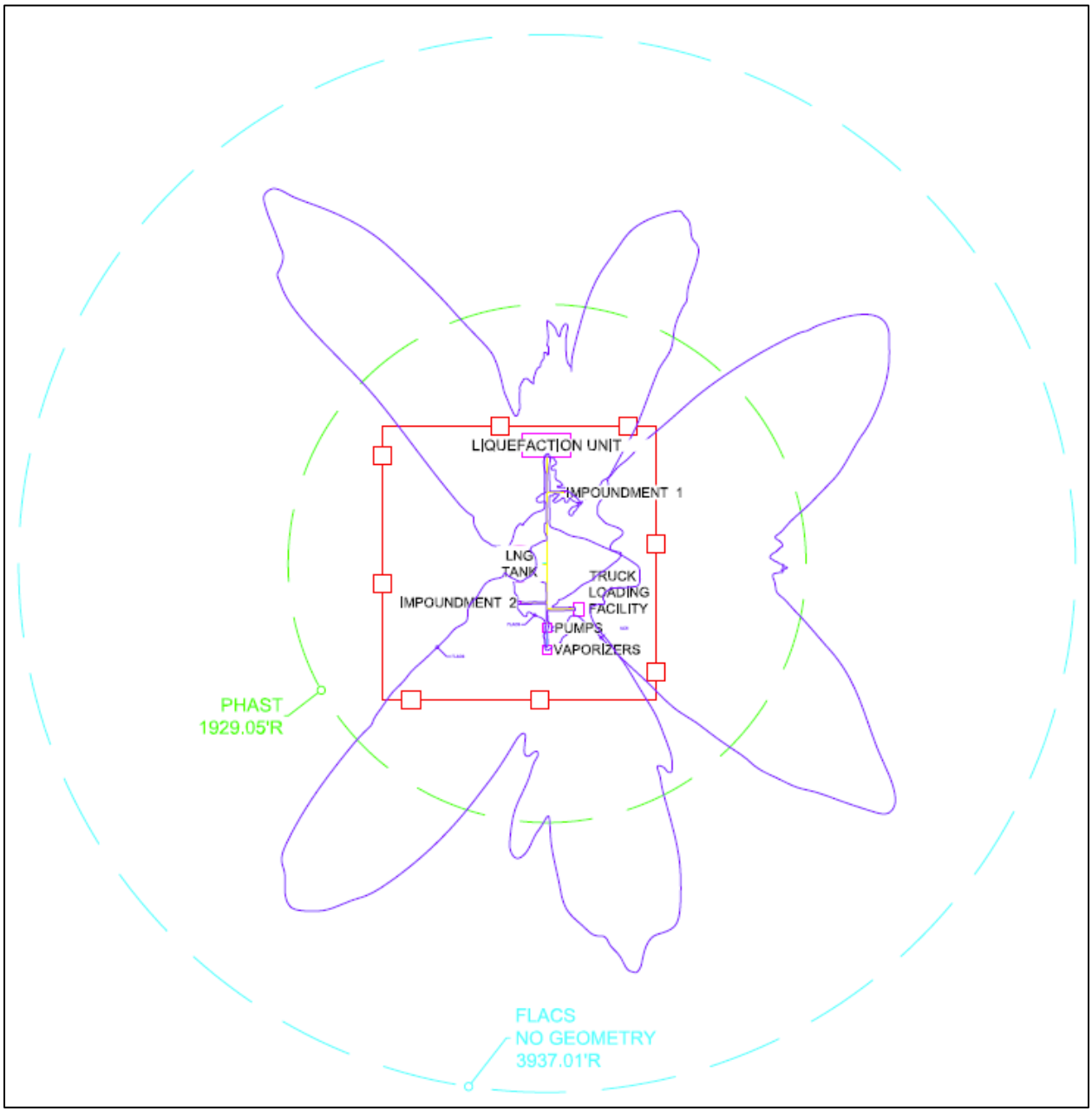

Figure 23.1-4: LP Sendout Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-4 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southeast, and Southwest.

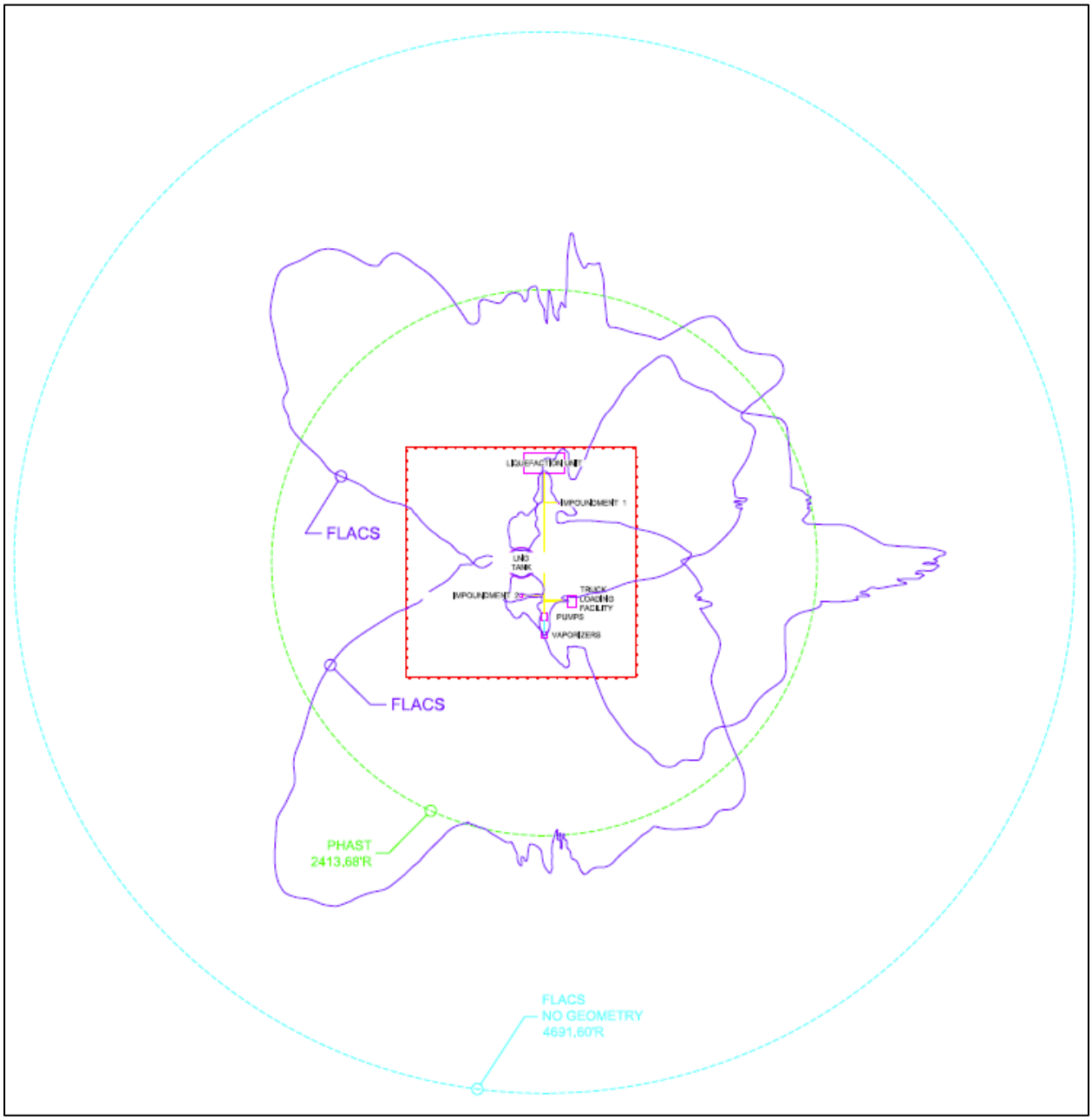

Figure 23.1-5: LP Sendout Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-5 include (1) a release direction to the North with winds blowing to the North, Northwest and Northeast, (2) a release direction to the East with winds blowing to the East, Northeast and Southeast, and (3) a release direction to the South with winds blowing to the South, Southeast, and Southwest.

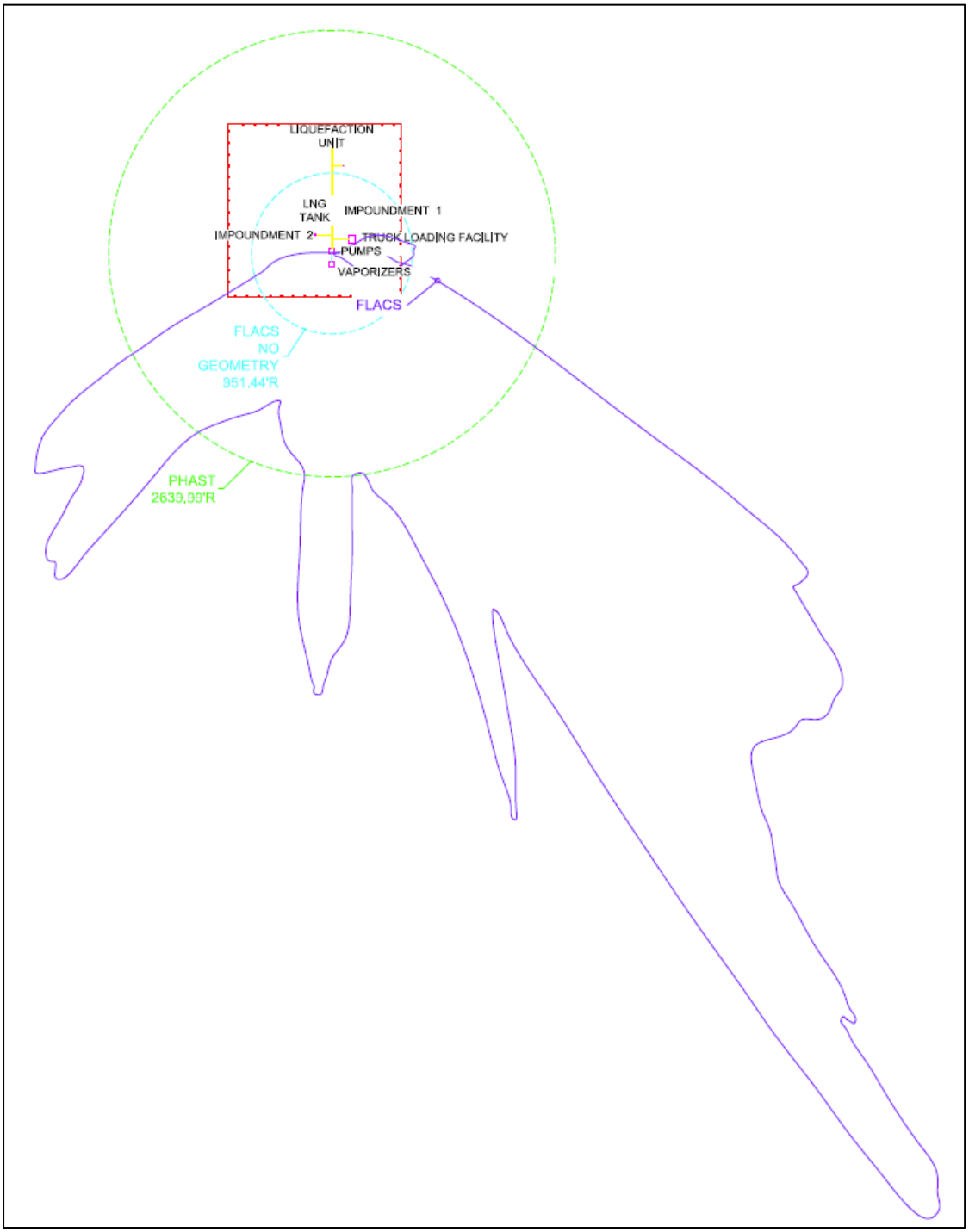

Figure 23.1-6: HP Sendout Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-6 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast and (2) a release direction to the South with winds blowing to the South, Southeast, and Southwest.

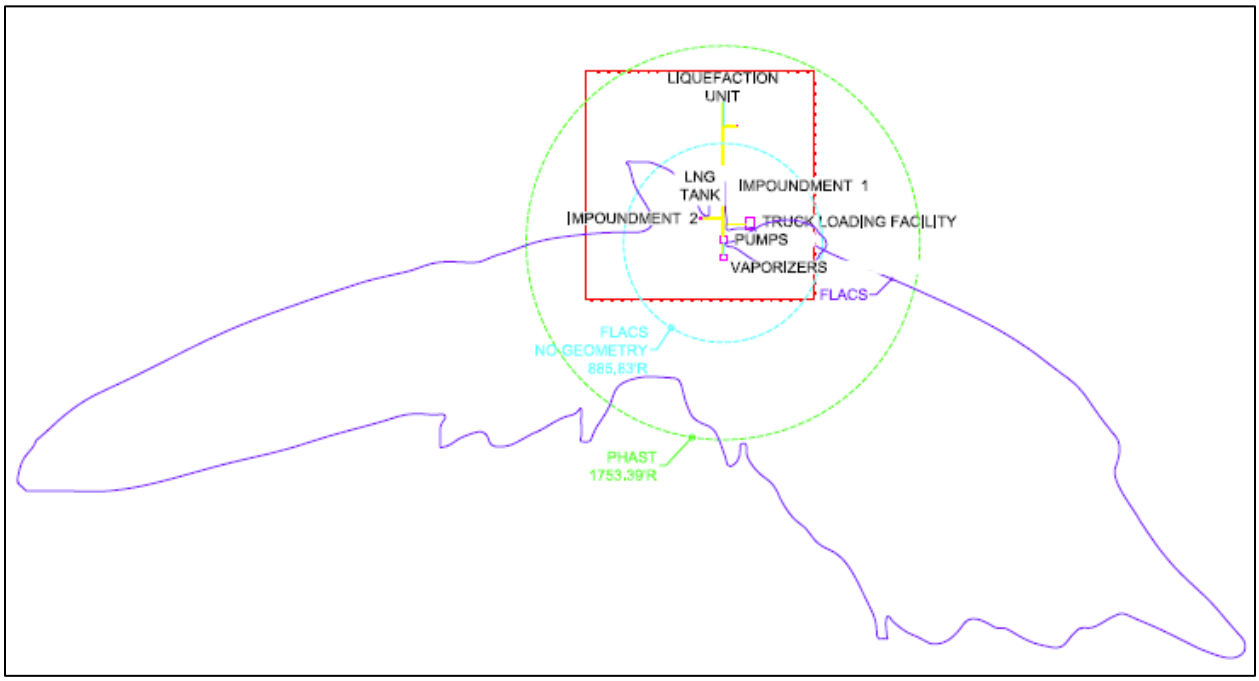

Figure 23.1-7: HP Sendout Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-7 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast and (2) a release direction to the South with winds blowing to the South, Southeast, and Southwest.

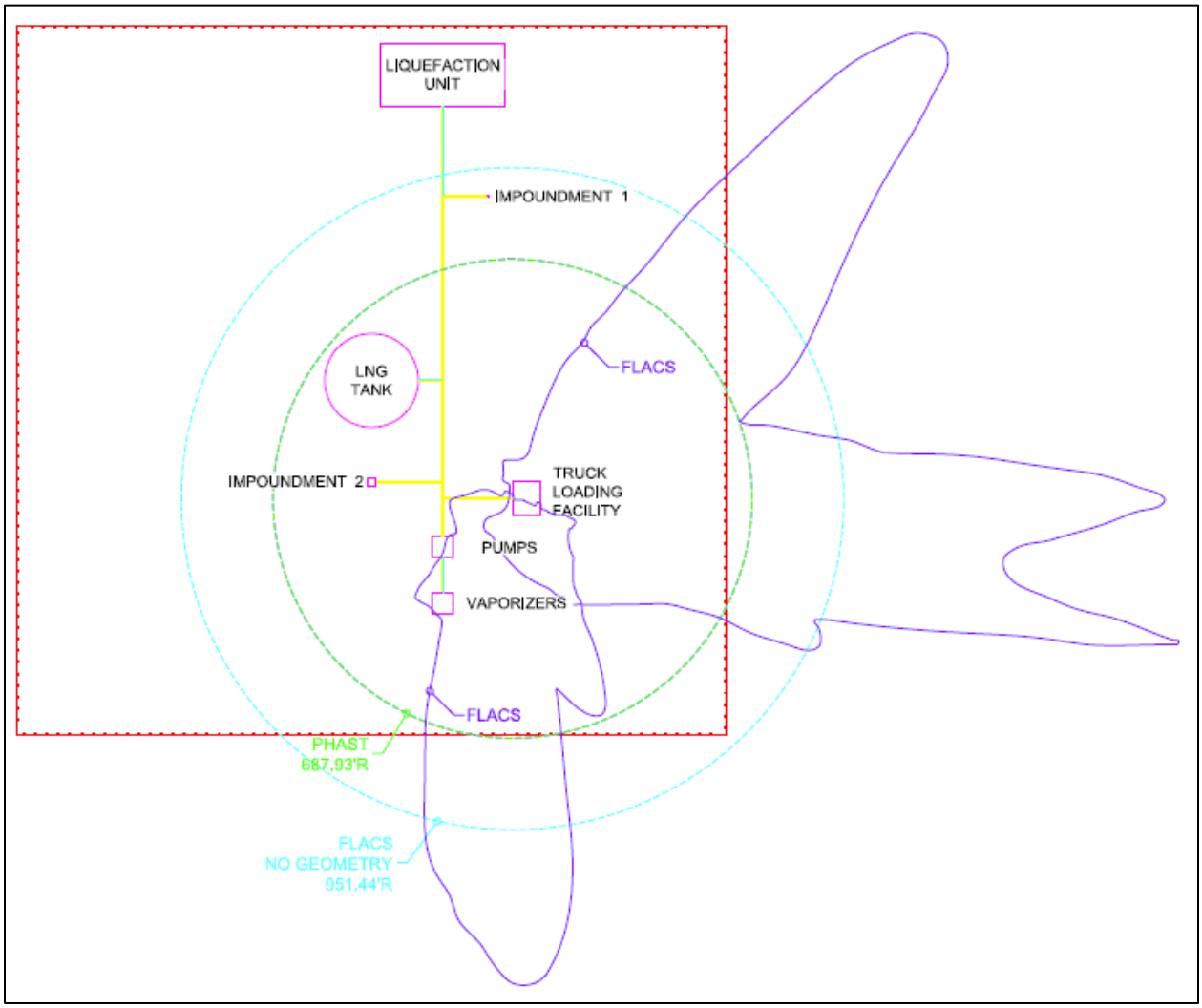

Figure 23.1-8: Truck Loading Line (2 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-8 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast and (2) a release direction to the South with winds blowing to the South, Southeast, and Southwest.

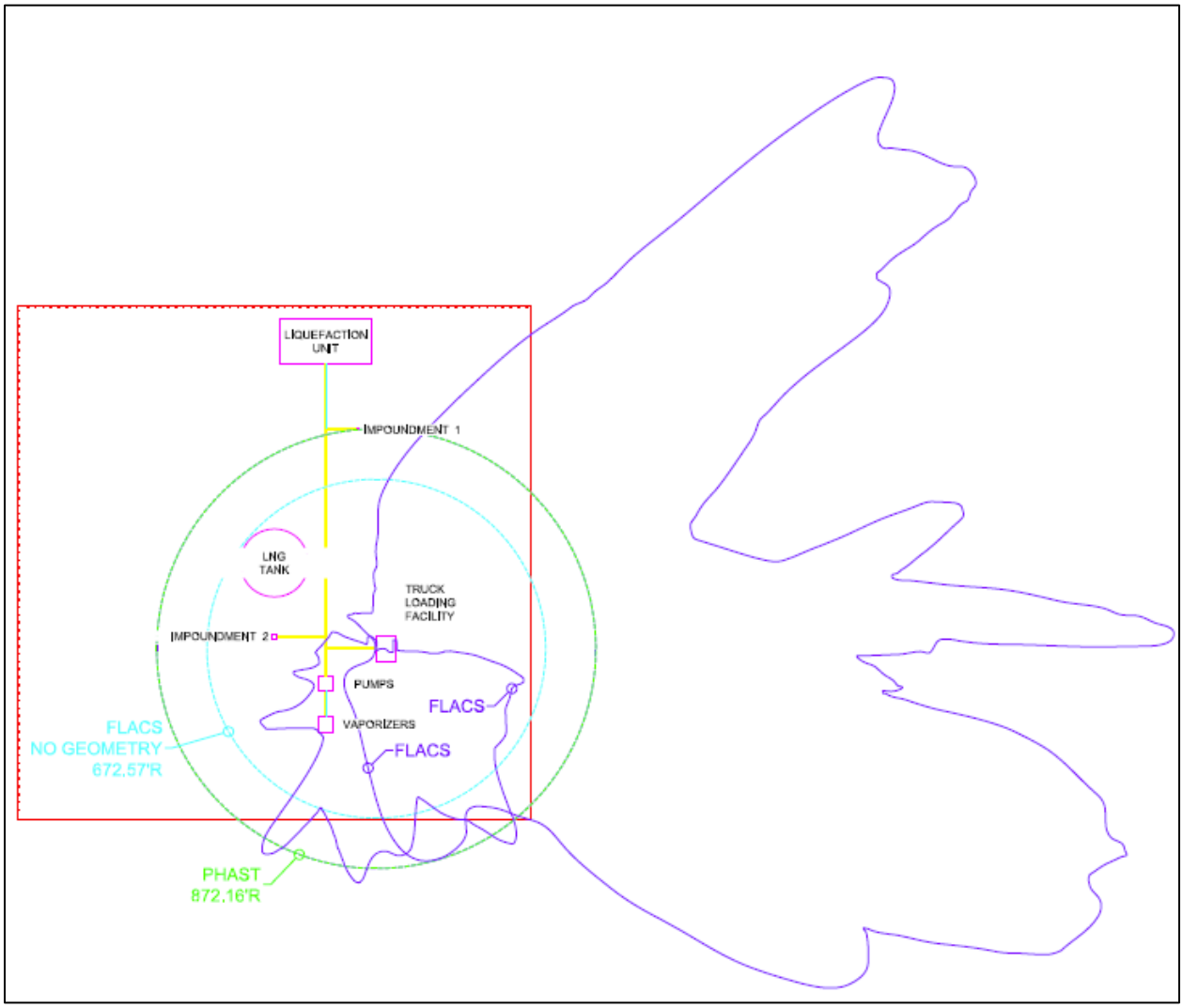

Figure 23.1-9: Truck Loading Line (1 m/s, 0.03m)

The FLACS results illustrated in Figure 23.1-9 include (1) a release direction to the East with winds blowing to the East, Northeast and Southeast and (2) a release direction to the South with winds blowing to the South, Southeast, and Southwest.

Results Discussion:

For the rundown line, the results are generally comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 2-3 between the Phast and FLACS models.

For the LP sendout line, the FLACS release with geometry and the FLACS release without geometry are much larger than the Phast results. The results are within a factor of 2 between the Phast and FLACS models.

For the HP sendout line, the FLACS release without geometry is much smaller than the Phast results and FLACS release with geometry is much larger than the Phast results. This scenario has one of the largest differences in dispersion distances across the models. The results are within a factor of 2-3 between the Phast and FLACS models.

For the truck loading line, the results are generally comparable across the different models overall with slight variations in the actual dispersion distances. These differences are expected due to the different methods each model uses to model dispersion. The results are within a factor of 1.5 between the Phast and FLACS models.

23.2 LNG Conveyance

The design spills used as the basis for conveyance to impoundments are detailed in Table 23.2.

Table 23.2: LNG Conveyance Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10-Minute Spill Volume (ft^3)	Spill Containment Dimensions (ft x ft)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)
Rundown Line (P-1)	48,454	288.75	4 x 4	8 x 8 x 5	320
LP Sendout Line (P-5)	930,317	5,543.99	4 x 4	20 x 20 x 15	5,600

Figure 23.2-1 illustrates the release location for the worst-case scenarios described in Table 23.2:

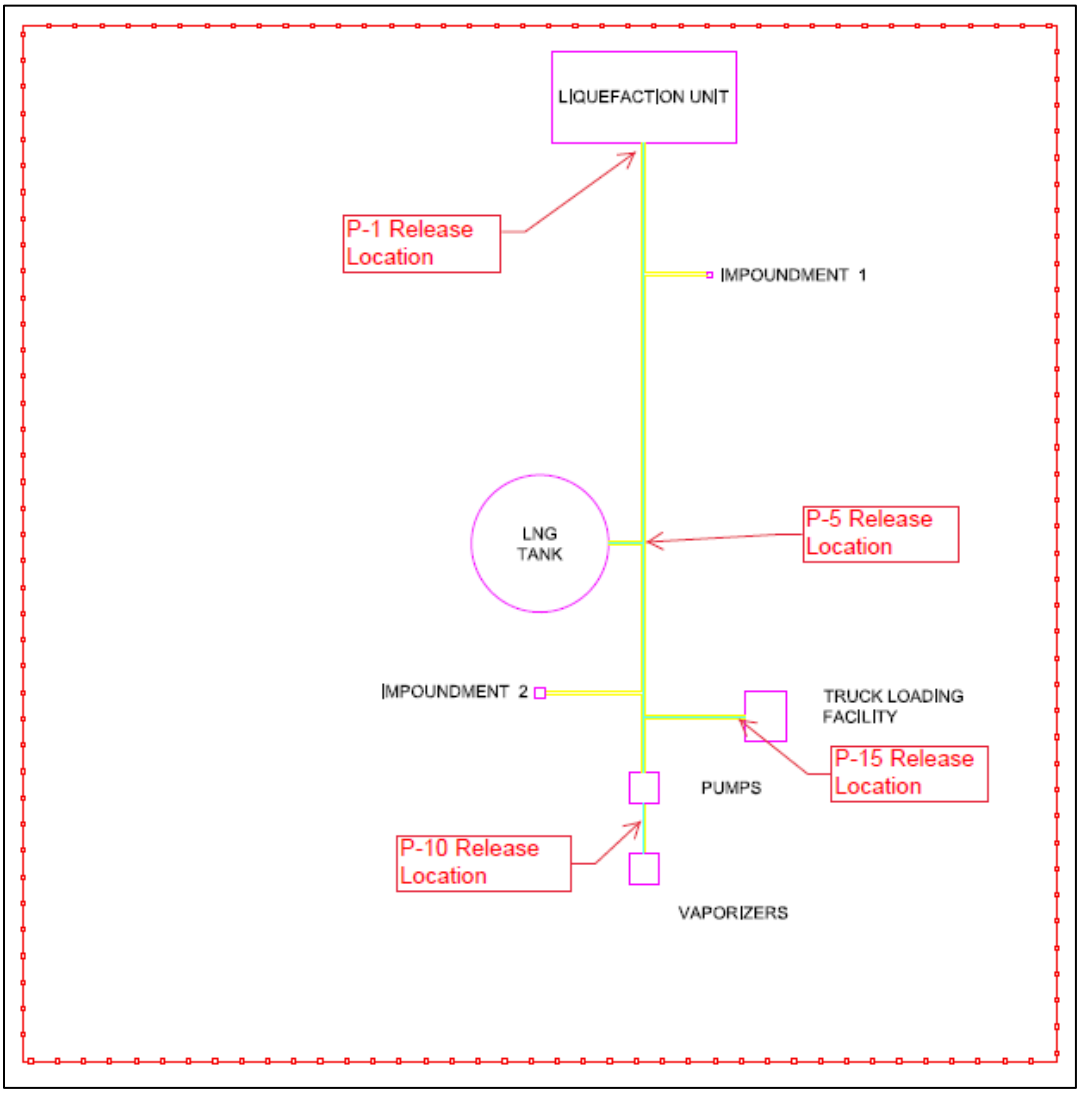

Figure 23.2-1: Conveyance Release Locations

All FLACS releases for LNG conveyance are for a release from the spill location as shown in Figure 23.2-1 into the spill containment system flowing towards the impoundment. The spill direction into the spill containment system is towards the impoundment. The results are presented in combined figures for winds blowing in the North, South, East, and West directions.

The results of the LNG conveyance to impoundment vapor dispersion modeling are illustrated in the following figures:

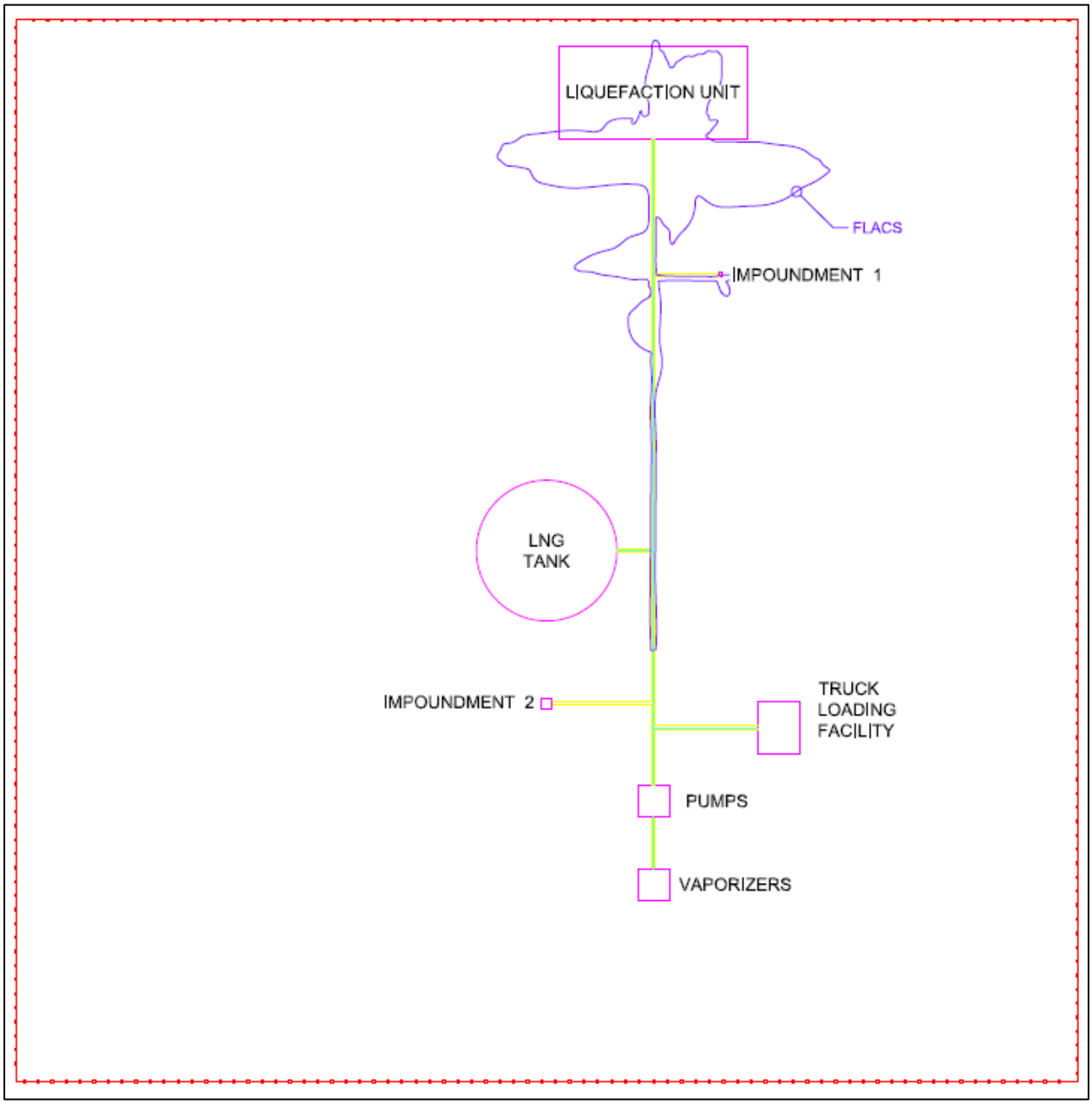

Figure 23.2-2: Rundown Line (2 m/s, 0.03m)

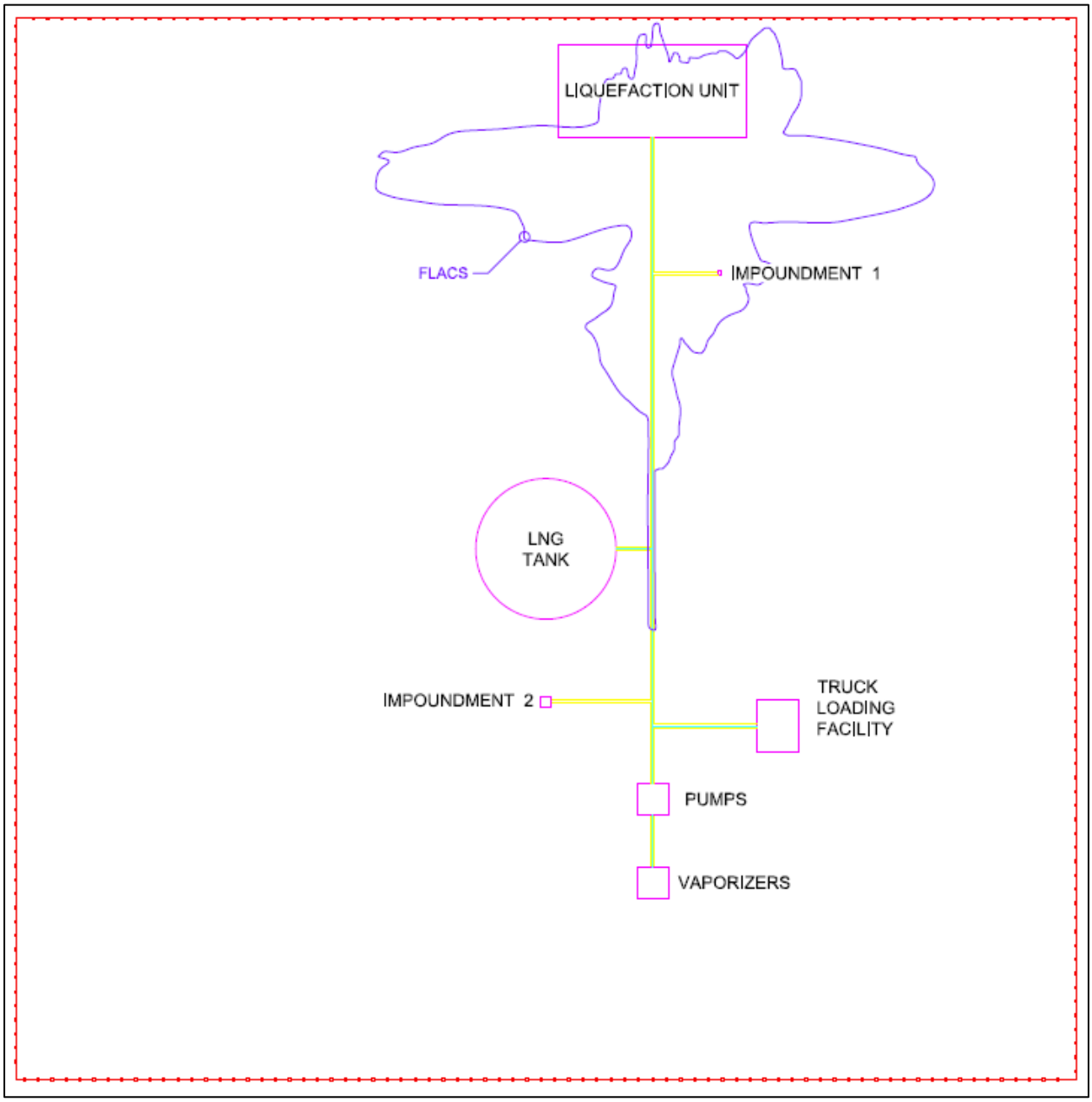

Figure 23.2-3: Rundown Line (1 m/s, 0.03m)

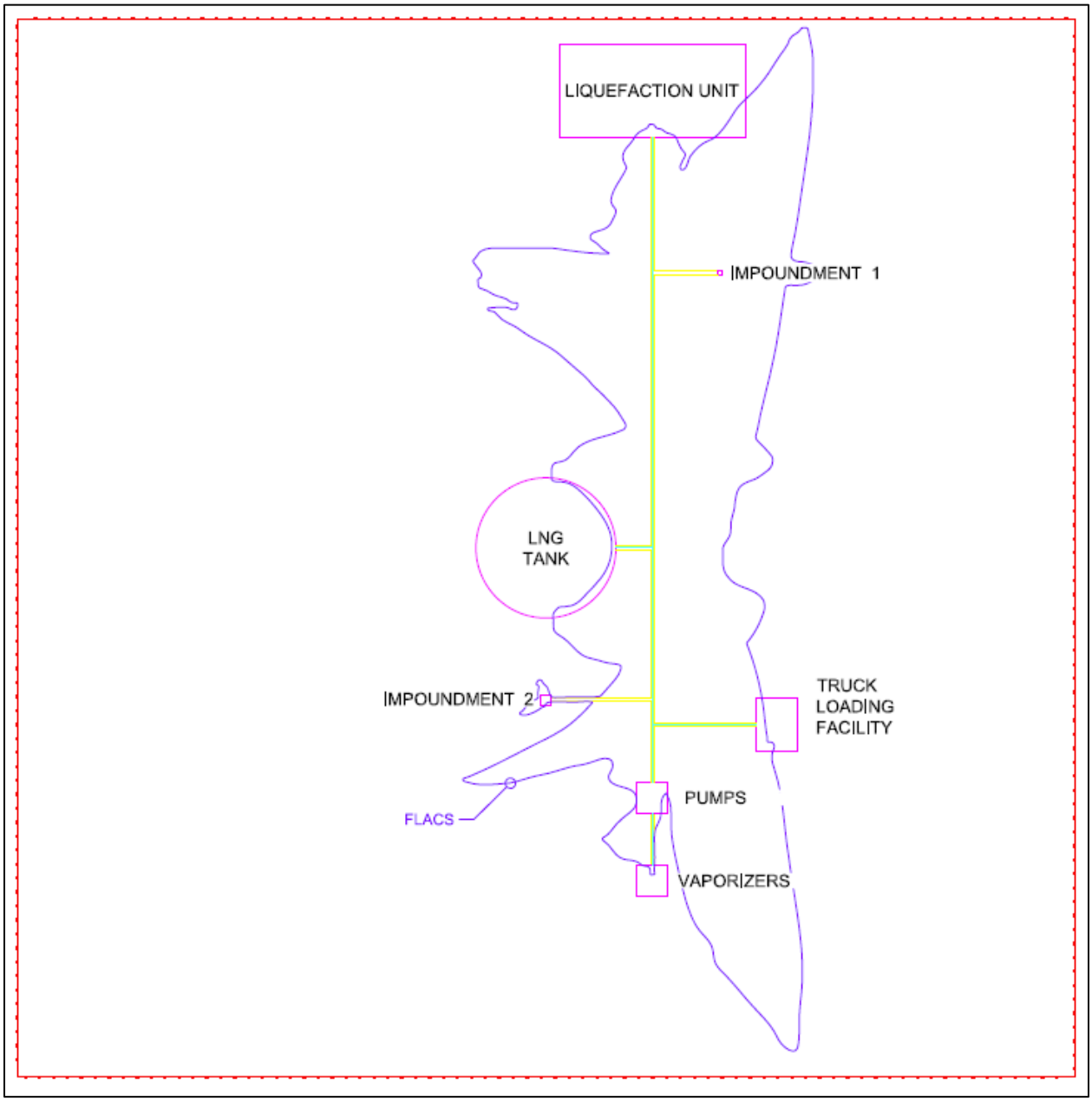

Figure 23.2-4: LP Sendout Line (2 m/s, 0.03m)

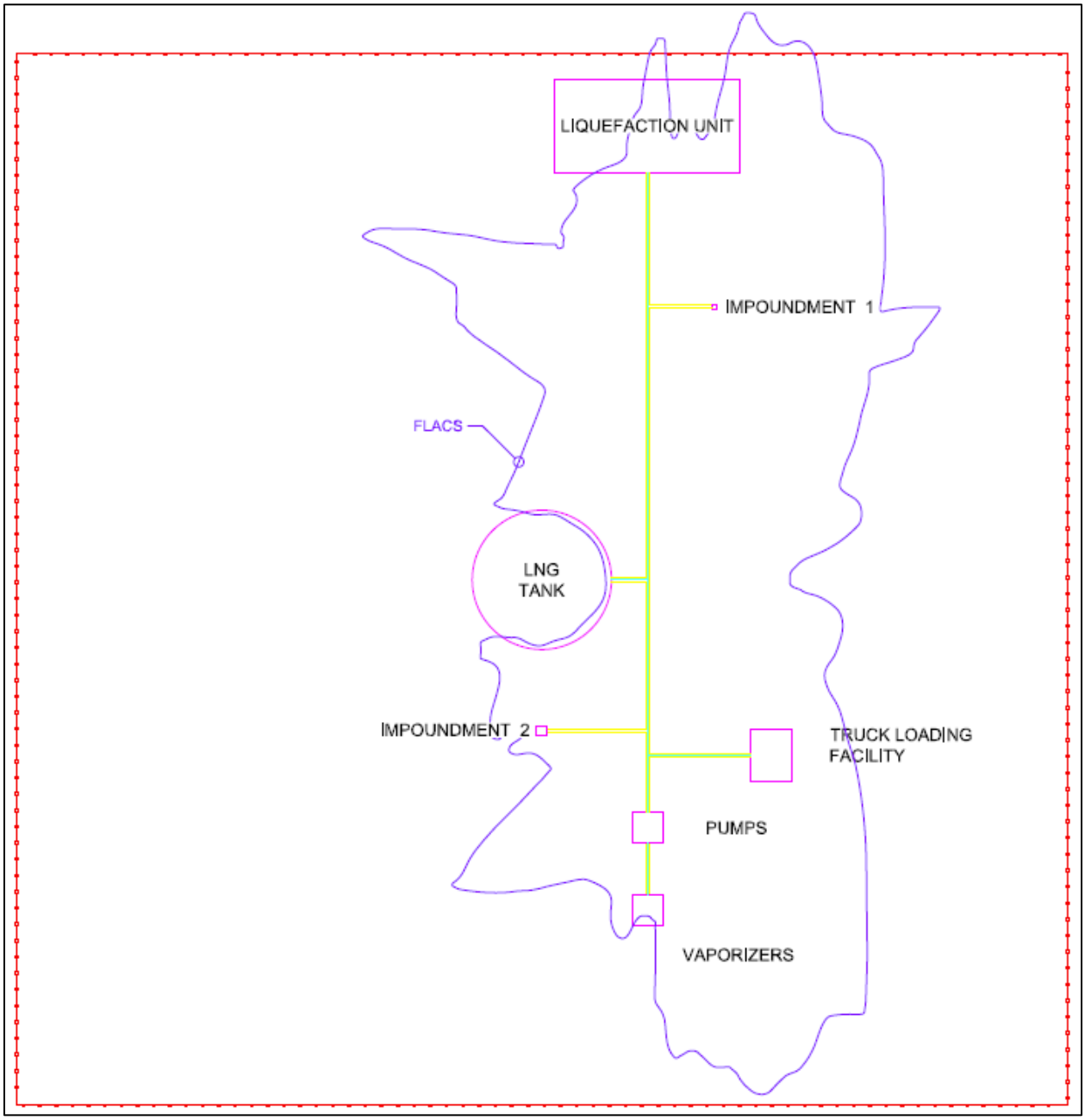

Figure 23.2-5: LP Sendout Line (1 m/s, 0.03m)

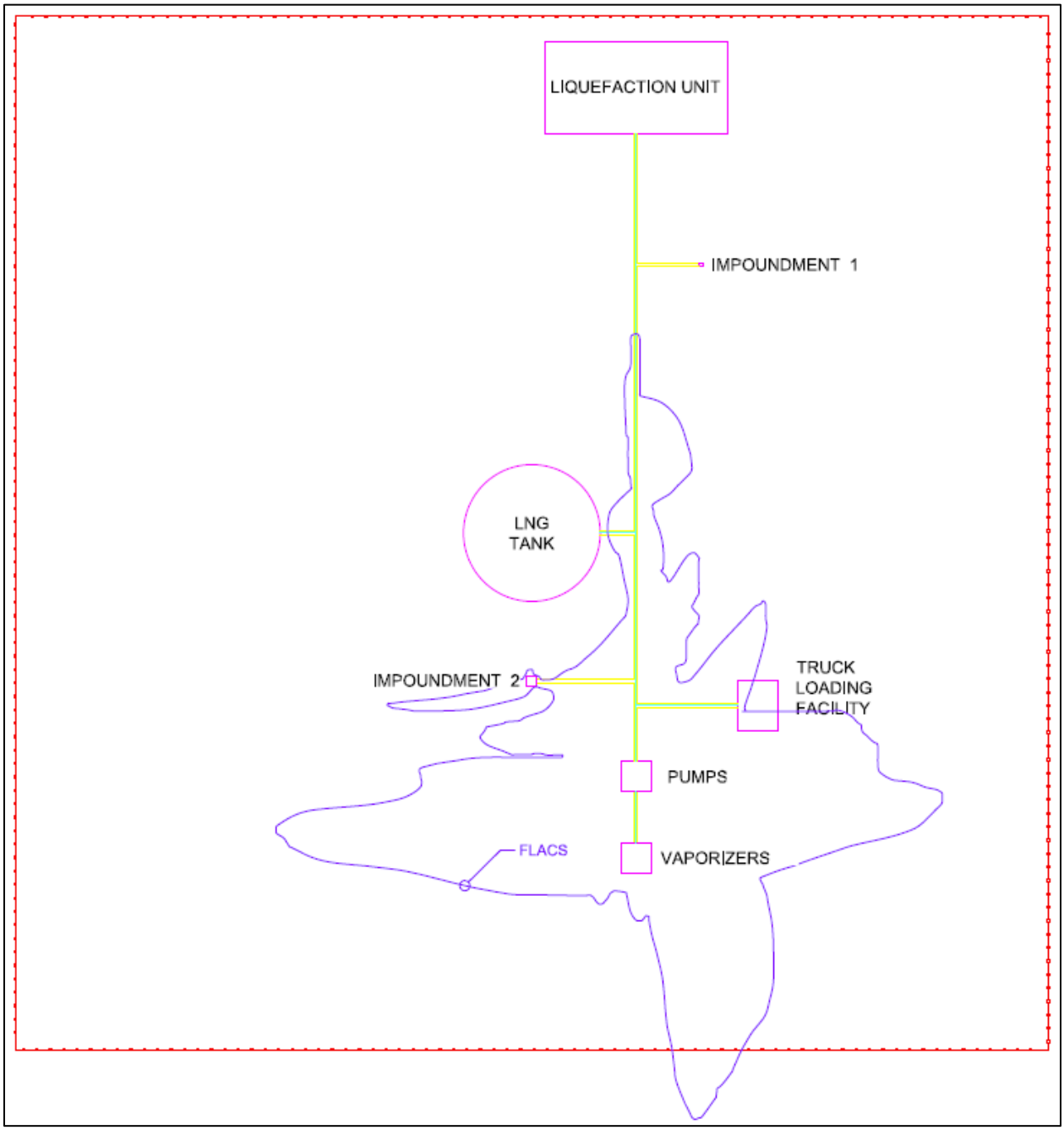

Figure 23.2-6: HP Sendout Line (2 m/s, 0.03m)

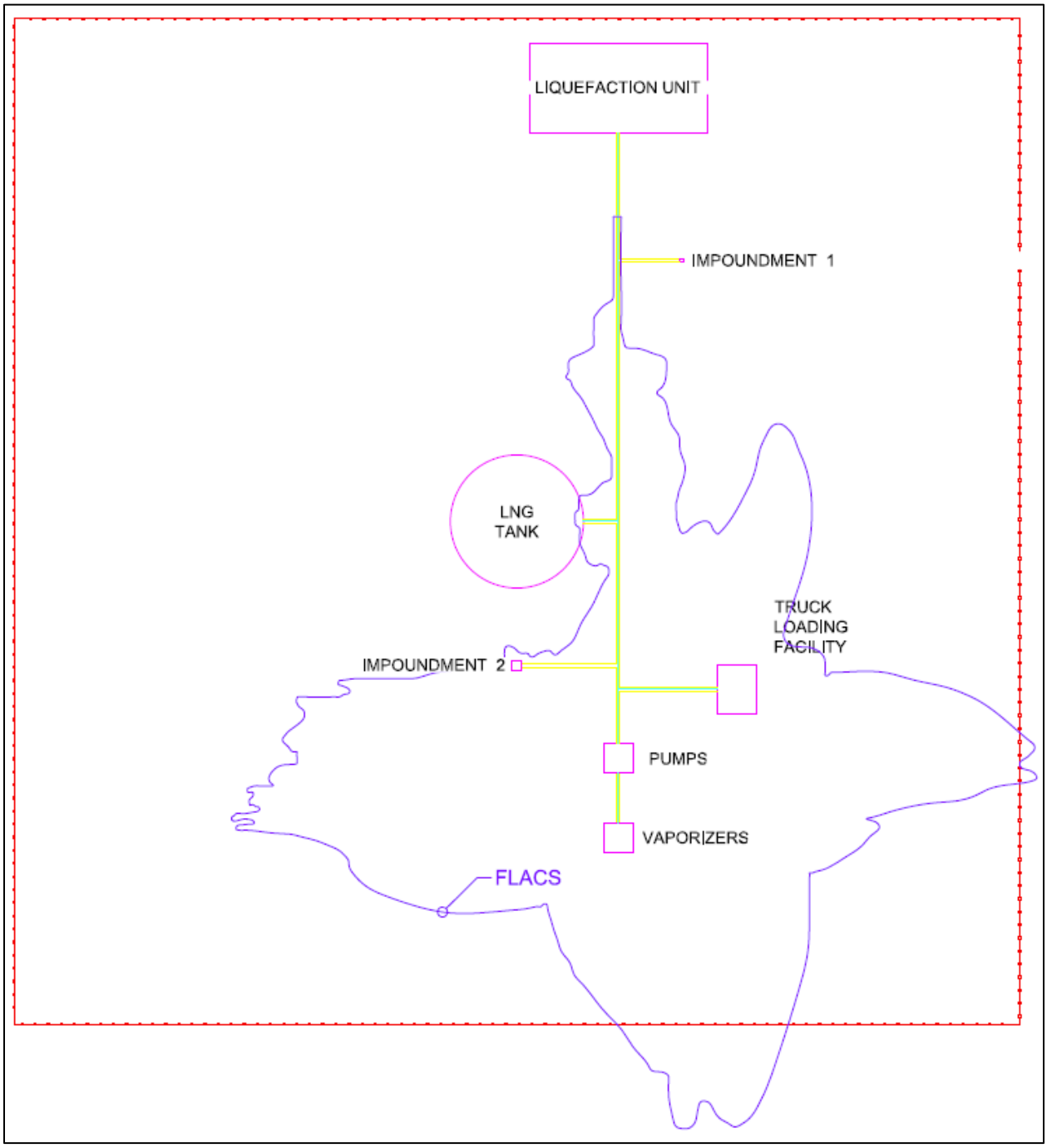

Figure 23.2-7: HP Sendout Line (1 m/s, 0.03m)

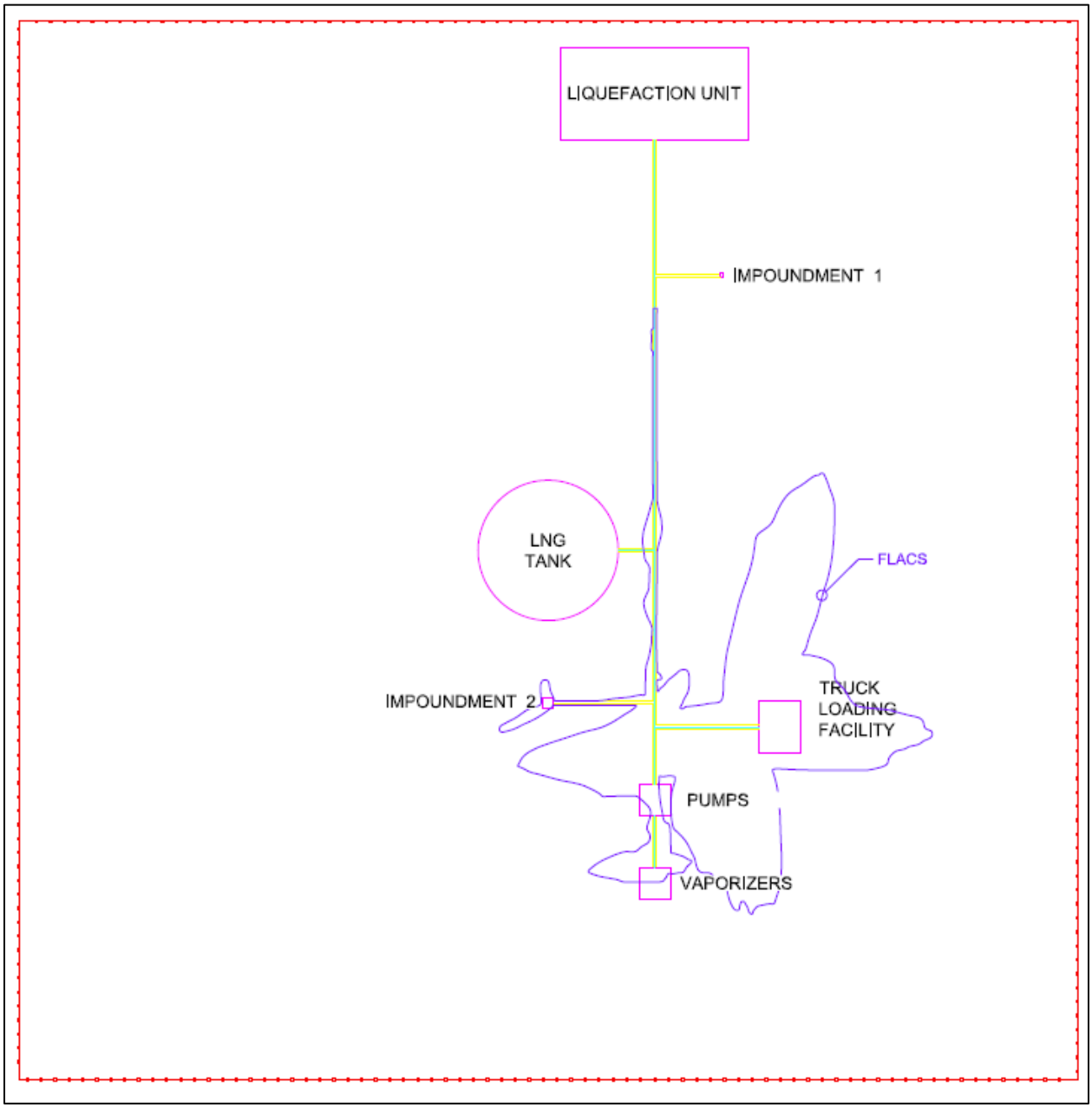

Figure 23.2-8: Truck Loading Line (2 m/s, 0.03m)

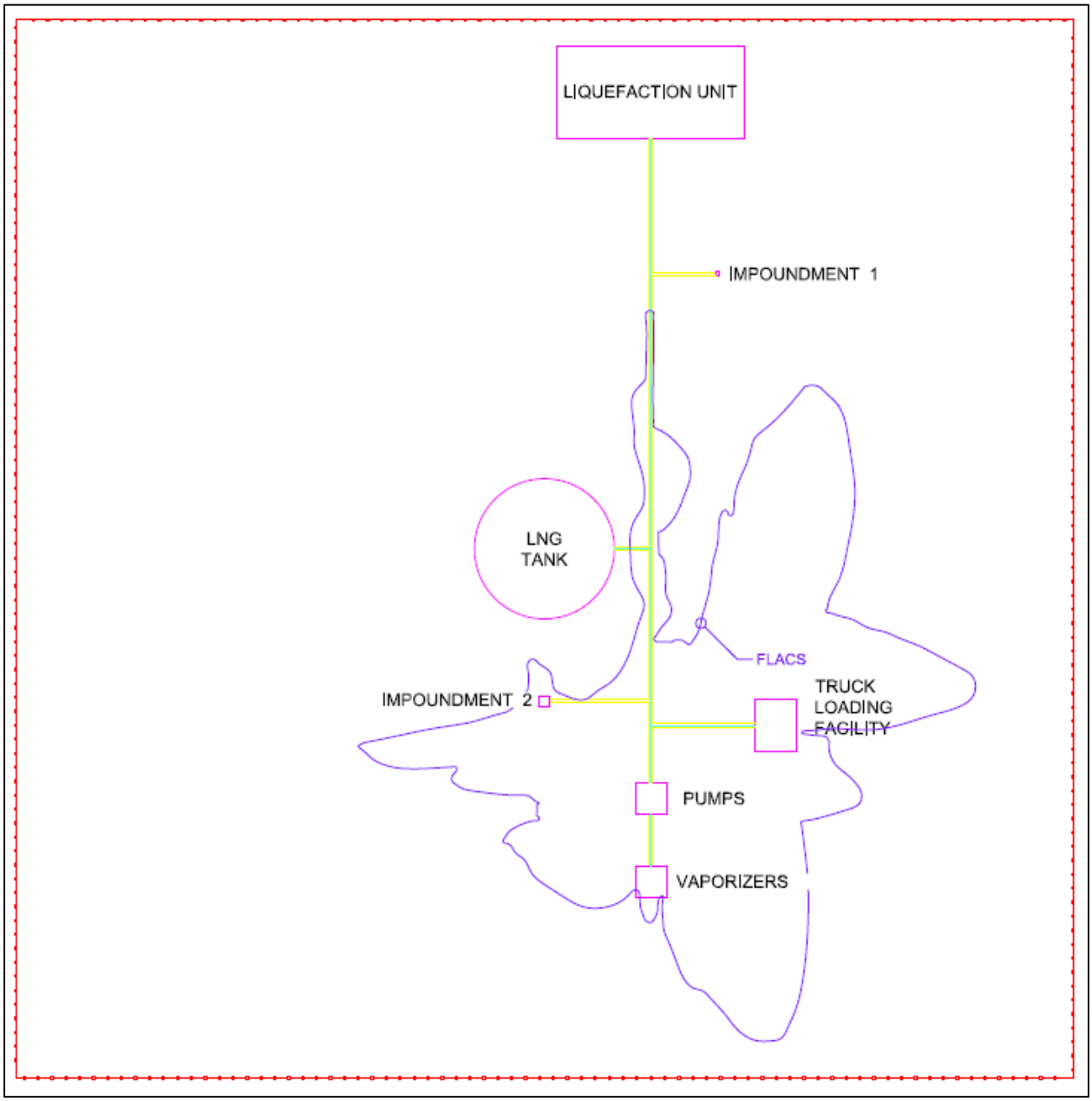

Figure 23.2-9: Truck Loading Line (1 m/s, 0.03m)

Results Discussion:

The FLACS results illustrated in each figure for the different wind speed and surface roughness values are for a single release into the spill containment system which flows into the impoundment. The results presented are combined results for winds blowing in the North, South, East and West directions.

The majority of the releases stay within the plant property line. The releases that extend beyond the facility property line can be mitigated with basic design optimizations.

All conveyance scenarios have significantly smaller vapor dispersion exclusion zones compared to the jetting and flashing exclusion zones.

23.3 LNG Impoundments

The design spills used as the basis for LNG spills into impoundments are detailed in Table 23.3-1.

Table 23.3-1: LNG Impoundments Sizing

Spill Source (Scenario)	Flow Rate (lb/hr)	10-Minute Spill Volume (ft^3)	Impoundment Dimensions (ft x ft x ft)	Impoundment Capacity (ft^3)	Impoundment #
Rundown Line (P-1)	48,454	288.75	8 x 8 x 5	320	1
LP Sendout Line (P-10)	930,317	5,543.99	20 x 20 x 14	5,600	2

As the LP sendout line, HP sendout line and truck loading line are all served by the same impoundment, only the LP sendout line was modeled as it had the largest flow rate into the impoundment.

Figure 23.3-1 illustrates the release location for the worst-case scenarios described in Table 23.3-1:

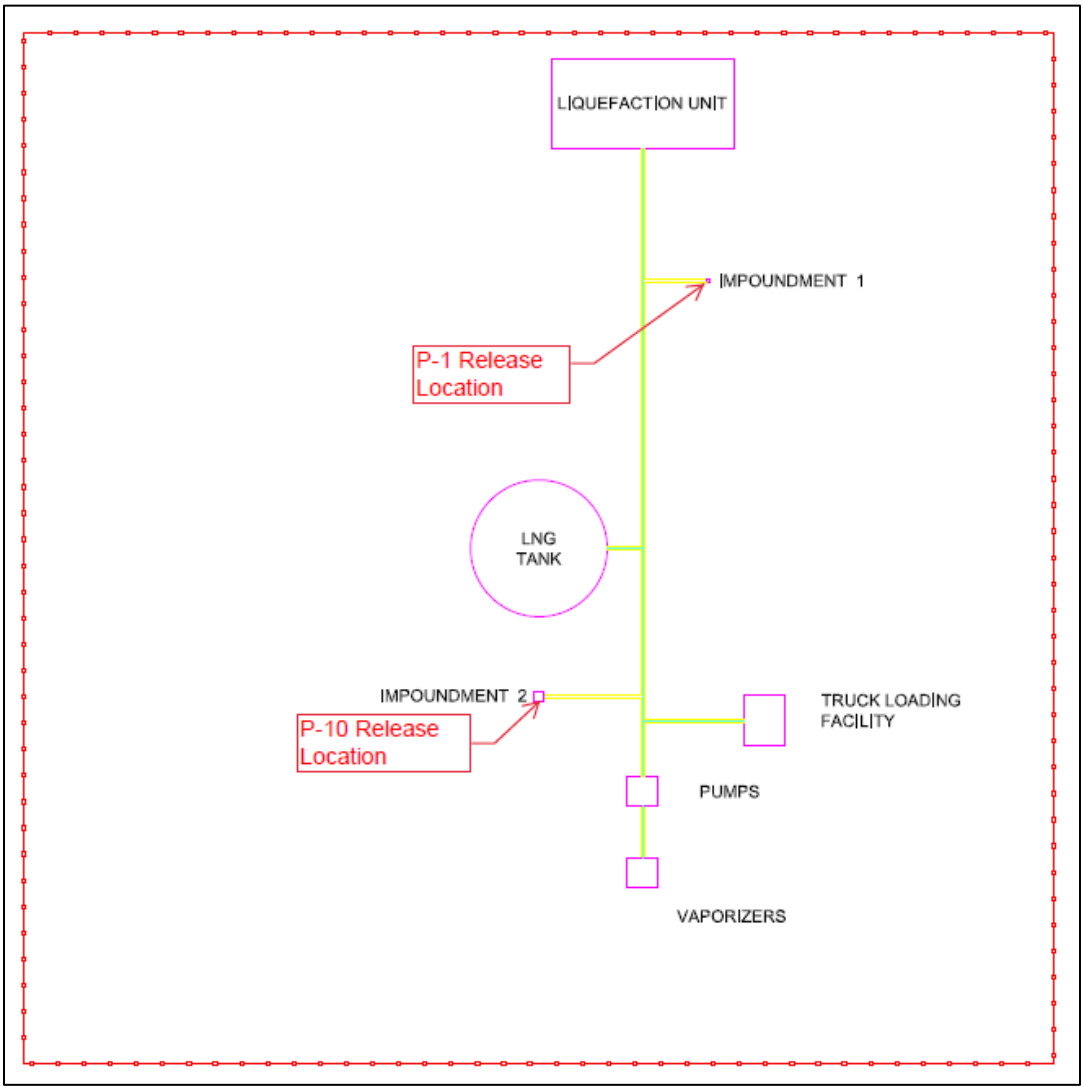

Figure 23.3-1: Impoundment Release Locations

The results of the LNG impoundment vapor dispersion modeling are detailed in Table 23.3-2.

Table 9.3-2: LNG Impoundments Vapor Dispersion Results

Spill Source (Scenario)	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast ½ LFL Distance (ft)	DEGADIS ½ LFL Distance (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)
Rundown Line (P-1)	2	0.03	227.98	82.88	213.25
Rundown Line (P-1)	1	0.03	306.91	91.47	262.47

Spill Source (Scenario)	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast ½ LFL Distance (ft)	DEGADIS ½ LFL Distance (ft)	FLACS Distance to ½ LFL (No Geometry) (ft)
LP Sendout Line (P-10)	2	0.03	450.08	453.04	770.99
LP Sendout Line (P-10)	1	0.03	613.47	448.01	787.40

The results of the LNG impoundment vapor dispersion modeling are illustrated in the following figures:

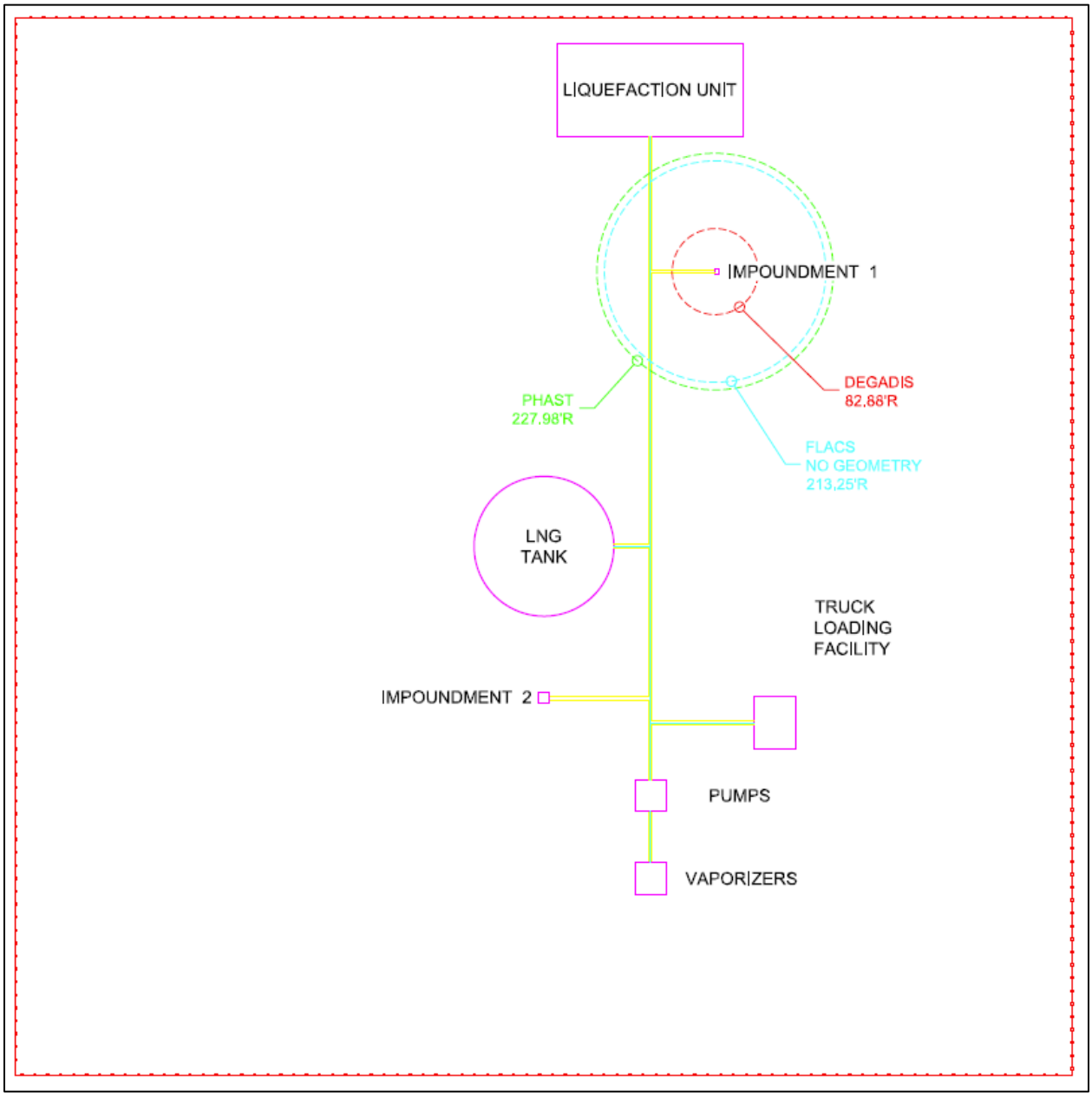

Figure 23.3-2: Rundown Line (2 m/s, 0.03m)

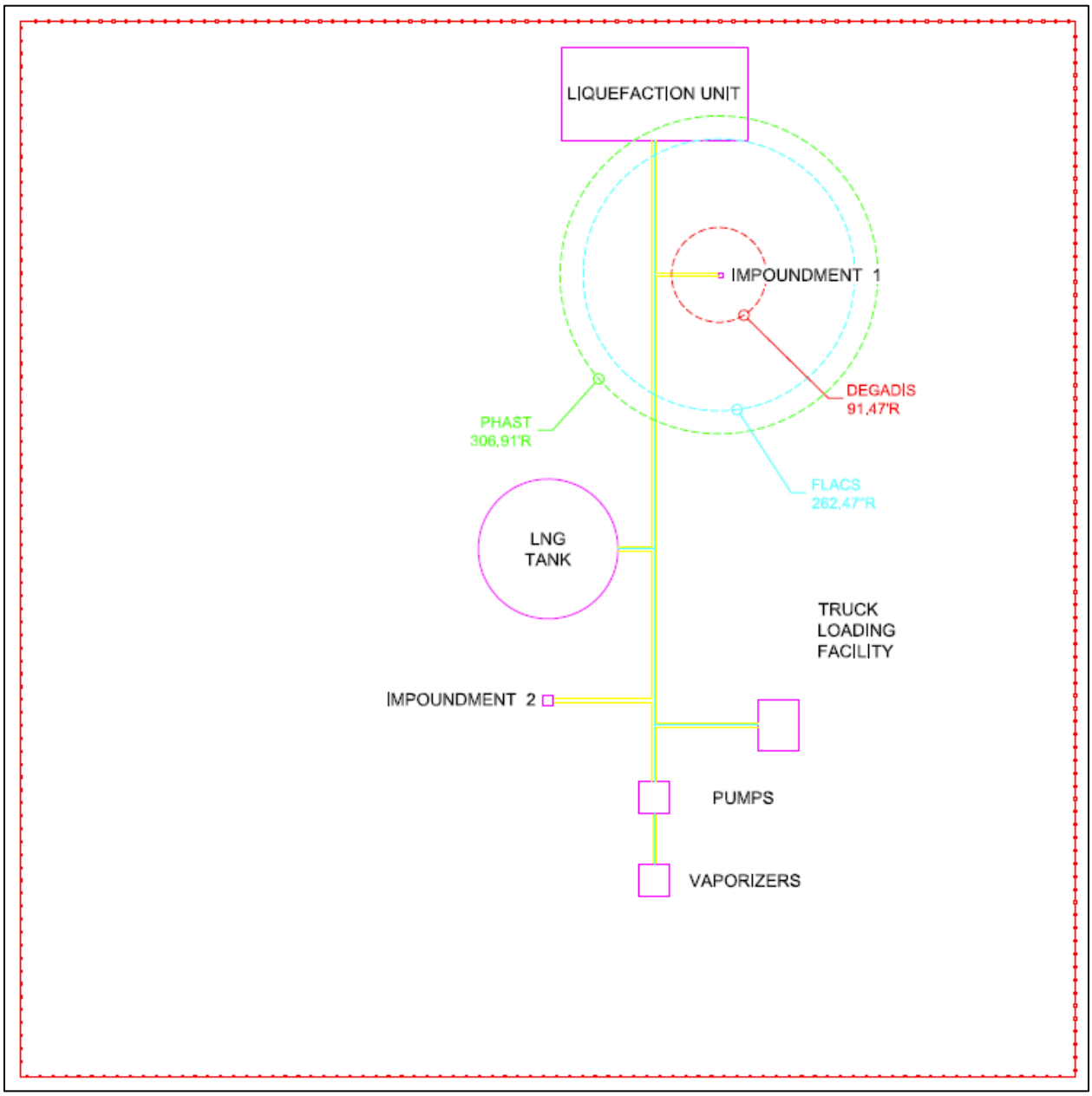

Figure 23.3-3: Rundown Line (1 m/s, 0.03m)

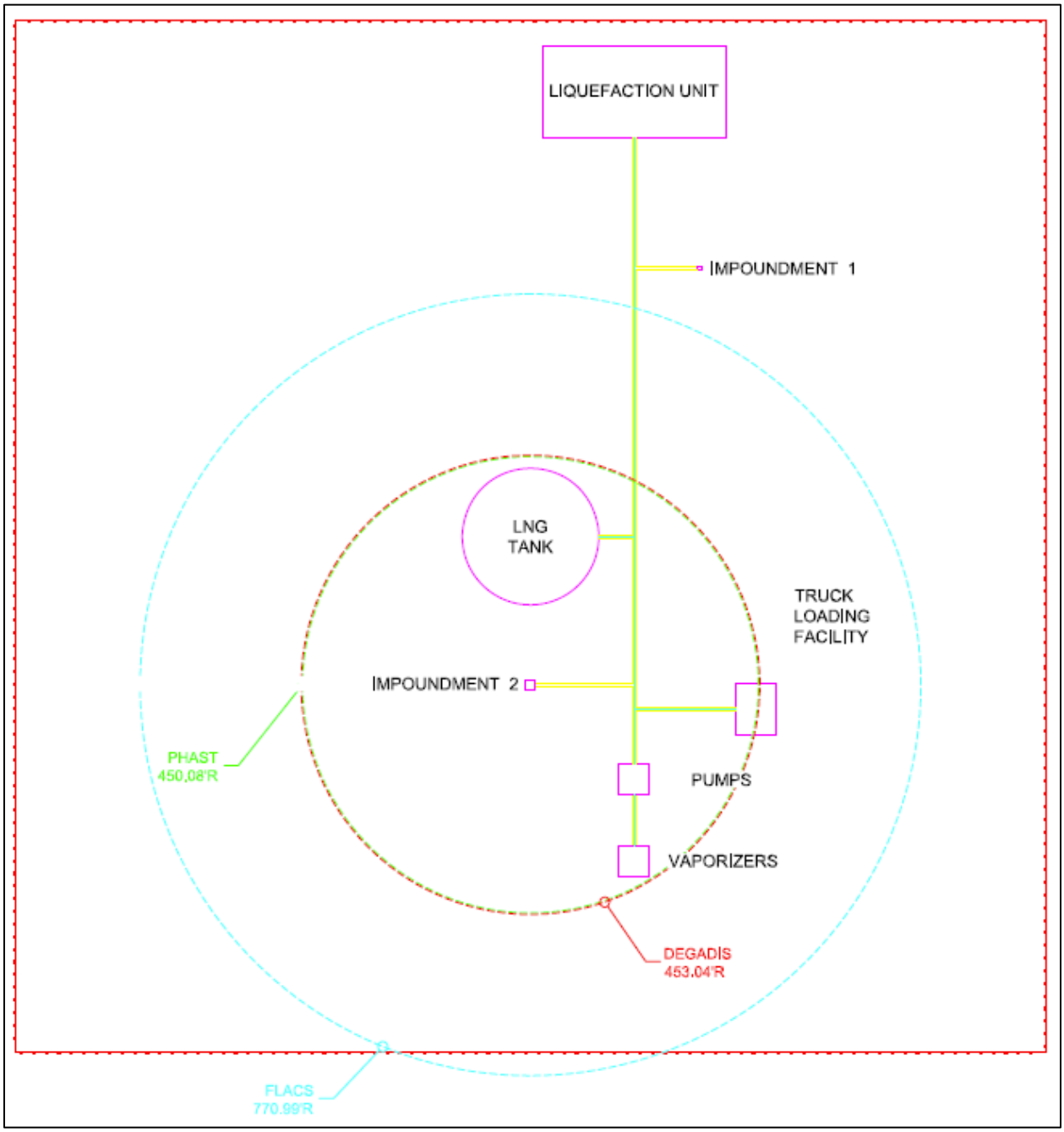

Figure 23.3-4: LP Sendout Line (2 m/s, 0.03m)

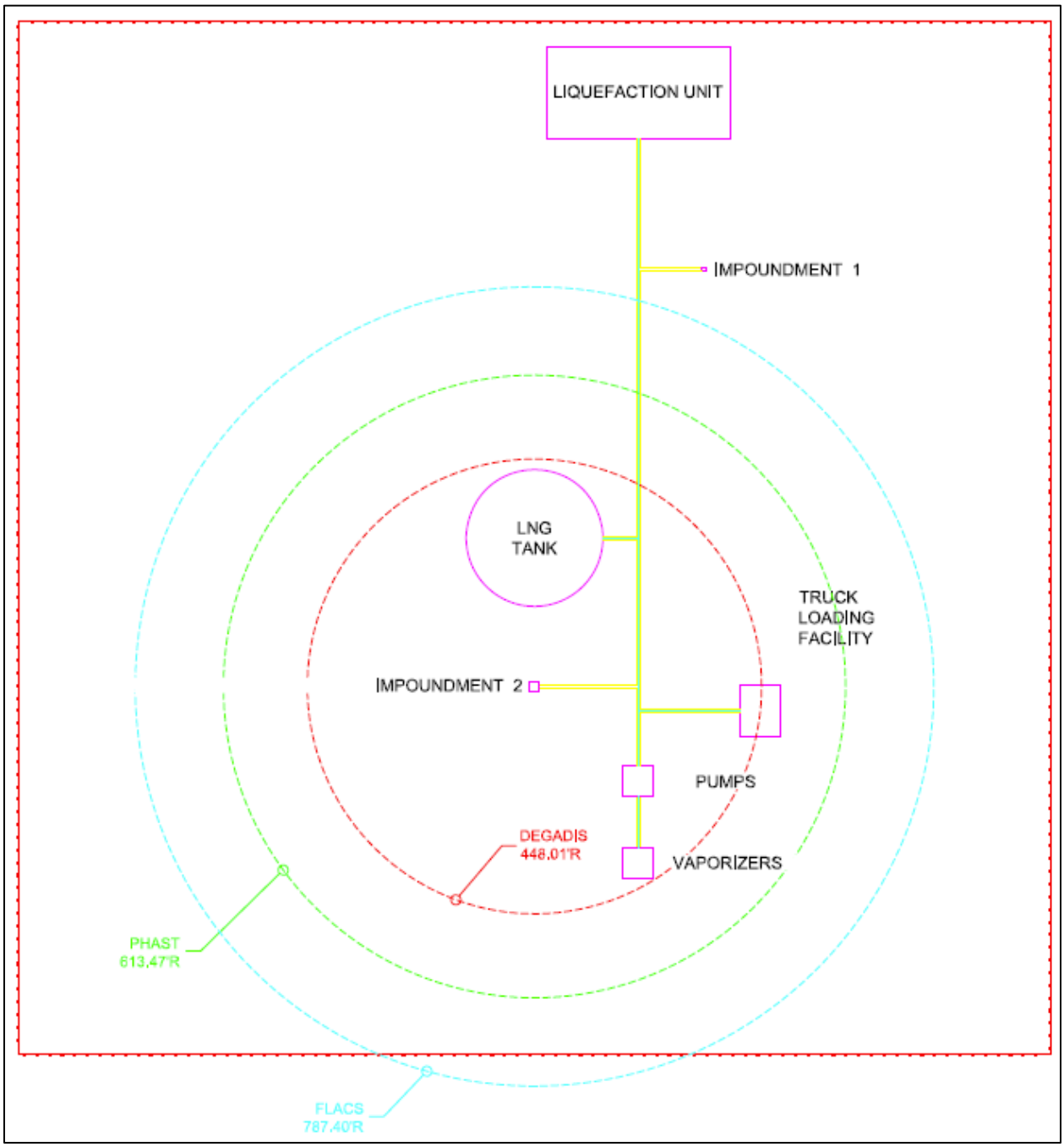

Figure 23.3-5: LP Sendout Line (1 m/s, 0.03m)

Results Discussion:

The results for the rundown line spill into Impoundment 1 show Phast and FLACS without geometry having very similar results with the DEGADIS results being smaller but reasonably on par with the Phast and FLACS results. The results are within a factor of 1.5 between the Phast and FLACS models and within a factor of 2-3 between the DEGADIS and Phast or FLACS models.

The results for the LP sendout line spill into Impoundment 2 show Phast and DEGADIS having very similar results with the FLACS without geometry model results being slightly larger but reasonable on par with Phast and DEGADIS. The results are within a factor of 1-2 across all models.

The FLACS model can take into account the depth of the impoundment, which can provide additional vapor holdup. The Phast model does not account for the depth of the impoundment, and therefore the FLACS results will be more representative. Therefore, the results are as expected.

For Phast and FLACS, the properties of regular concrete were used for the impoundment modeling. Use of insulating concrete and its properties would reduce the vapor dispersion distances.

All impoundment scenarios have smaller vapor dispersion exclusion zones compared to the jetting and flashing scenarios due to the high pressure release associated with jetting and flashing mechanism described in section 6 of this Report.

23.4 Overall Exclusion Zone

The overall exclusion zone for the facility is best represented by the FLACS model as that model can account for facility specifics, including; spill containment systems, process equipment, LNG tanks, piperacks, terrain and other facility geometric features. For the jetting and flashing, conveyance and impoundment modeling performed for the peakshaver facility, the overall exclusion zone is bounded by the jetting and flashing modeling as the extent of the jetting and flashing exclusion zones are further than the LNG conveyance and LNG impoundment exclusion zones.

For the rundown line, it is likely that with layout optimization and mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration.

For the LP sendout line, it is unlikely that with layout optimization and basic mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The full guillotine failure of the LP sendout line results in a very large spill, which may be problematic for smaller peakshaving facilities. This will require mitigation to maintain this spill within a property line.

For the HP sendout line, it is unlikely that with layout optimization and basic mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The full guillotine failure of the HP sendout line results in a very large spill which may be problematic for smaller peakshaving facilities. This will require mitigation to maintain this spill within a property line.

For the truck loading line, it is unlikely that with layout optimization and basic mitigation, the jetting and flashing results will be able to stay within a property line that can be built upon for this configuration. The full guillotine failure of the truck loading line results in a very large spill which may be problematic for smaller peakshaving facilities. This will require mitigation to maintain this spill within a property line.

Therefore, mitigation measures such as ESD and vapor fences will need to be considered to reduce the associated dispersion distances. Mitigation modeling is evaluated further in Section 30 of this Report.

The overall exclusion zone is illustrated in Figure 23.4 below:

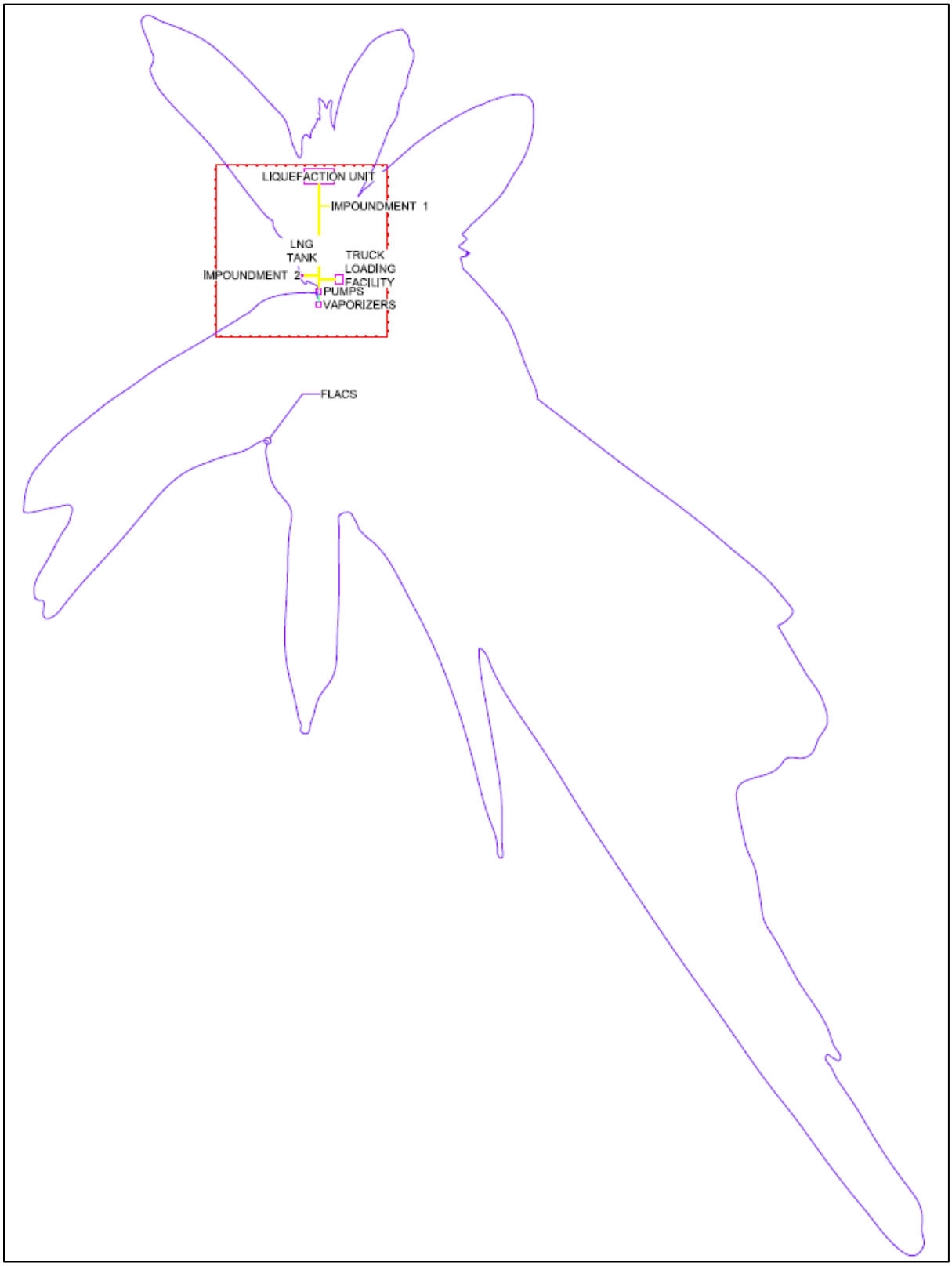

Figure 23.4: Overall Exclusion Zone

24 UNMITIGATED VAPOR DISPERSION RESULTS CONCLUSION AND RECOMMENDATIONS

The design spills selected to be modeled for all the modeling scenarios were based on application of the DOT PHMSA FAQ's (revised 12/7/2015). Based on the generic layouts for each facility, the application of the FAQ's result in large hole sizes and large design spills. As a result, many of the modeling scenarios extend beyond the property lines on each facility plot plan.

Therefore, for many scenarios mitigation modeling is necessary to demonstrate compliance with 49 CFR §193.2059.

Current requirements from DOT PHMSA, as detailed in section 2.5 of this Report, prescribe that applicants consider the effects of jetting and flashing, conveyance of LNG to impoundments, and LNG spills into impoundments as part of a vapor dispersion analysis. The results of the modeling performed by this Project illustrate that for all generic plot plans and modeling scenarios, the jetting and flashing releases resulted in further distances than the conveyance and LNG into impoundment releases.

TASK 4B: MITIGATED VAPOR DISPERSION EXCLUSION ZONE RESULTS COMPARISON

25 MITIGATION MEASURES

Several mitigation measures can be applied to vapor dispersion modeling to potentially reduce vapor dispersion exclusion zones. This report identifies the effectiveness of vapor fences, ESD valves, PERC valves and breakaway couplings commonly used at LNG facilities. Many other features commonly used, such as insulated concrete, were not included in this analysis.

25.1 Vapor Fences

A vapor fence is a barrier placed in an LNG facility to provide vapor holdup, or to provide an obstacle to reduce vapor dispersion distances. Vapor fences can be modeled with optimized dimensions (height and length). The fences can also have varying amounts of porosity which determines the amount of vapor that can leak through the fence. A wide range of materials and strengths can be utilized based on the purpose of a vapor fence. Vapor fences near a release can be utilized to reduce the momentum of a jet, but must be designed in a more robust fashion to handle the jetting temperatures and pressures. Vapor fences located away from the release may not experience the higher pressure or lower temperatures of a jet and may be designed with lighter materials.

Figure 25.1 provides two examples of vapor fence and illustrate the broad range of design. The left side image is a security fence with fabric covering and the image on the right is a solid, concrete wall, similar to a highway sound wall. For this project, we will assume vapor fences are made from solid materials which provide 0% porosity.

Figure 25.1: Vapor Fence Examples

25.2 ESD Valves

LNG facilities include ESD systems which can safety shutdown the LNG facility in the event of an abnormal operation. ESD systems can be activated by numerous devices as dictated in the project-specific cause and effect matrices. The activation devices can be from internal system monitoring, such as tank level gauges or external monitoring such as flammable gas detection. Gas detectors typically have a Pre-Alarm (20% LFL) and Alarm (40% LFL) set point. Typically, hazard detection will require 2 out of N (2ooN) monitoring or Alarm status for activation prior to initiating ESD. These programming features allow for operator intervention to check plant conditions and reduction in false alarms.

For this Project, an assumption is made that the ESD system is activated by hazard detection devices and therefore this Project will determine the time from spill initiation to ESD activation. It is understood that all LNG projects may have different control systems and therefore this may not be representative for all LNG projects. This Project assumes the following activation process:

- An LNG release occurs from plant piping or equipment consistent with the design spill sizes selected and modeled in Task 4.
- The vapors from the LNG release disperse as shown in Task 4 and are detected by a gas detector(s). For scenarios with high rainout fractions, the liquid portion of a release is collected in spill containment systems which are installed with low temperature detection. The Task 4 results indicate 50% LFL, whereas the detectors will alarm at 40% LFL.
- The gas detector(s) send a Pre-Alarm signal followed by an Alarm to the DCS, the DCS processes the signal, and the DCS sends a signal to a valve actuator to activate the ESD valve.
- The valve is closed by the actuator to safely shut down the process and stop the source of LNG flow to the leak.

To determine the appropriate timeframes for each of these steps several vendors were consulted to determine activation times based on equipment typically procured for LNG facilities.

- Hazard Detection Devices

A Det-tronics Infrared Hydrocarbon Gas Detector, Open Path Eclipse, Model OPECL was chosen as a sample detector. Rather than spot-type detection which provide a more limited scan area, this detector provides continuous monitoring of flammable gas concentrations in the range of 0 to 5 LFL – meters. Similar to the spot-type detectors, the path detectors will Pre-Alarm at 1 LFL-meter and Alarm at 2 LFL-meter. The system consists of two stainless steel modules – a transmitter and a receiver. Both modules are installed at the same elevation and are aligned to point directly at one another. This type of detector is ideal for outdoor environments and certified for Class I, Division 1 and Division 2 hazardous areas.

The detector illuminates a direct linear path from the transmitter to the receiver. As flammable hydrocarbon gasses intersect the light beam between the two modules, certain IR wavelengths are absorbed by the gas while other wavelengths are not. The amount of IR absorption is determined by the concentration of the gas. These gas detectors are factory calibrated for methane, but are also suitable for ethane, propane, and butane.

The gas detectors have a detection range of up to 150 meters (492 feet) and a response time of under 5 seconds.

For facilities which have spot type detectors, a Det-tronics IR Gas Detector, Pointwatch Eclipse, Model PIRECL specifies a response time from 4.8-7.6 seconds to detect a leak[11].

- Communication Cables

  A single twisted pair cable will typically connect the gas detector to the HDMS system which communicates with the DCS. Common cables can transmit signals in under a fraction of a second.

- Control System

  A DeltaV controller was chosen as a sample DCS system. This system has a scan rate of 0.1-0.2 seconds for high priority items. The system has scan rates of 0.5-5 seconds for medium priority items and scan rates of 10-60 seconds for low priority items[12]. Communication signals from the HDMS are considered a high priority item.

- Valve Actuator

  A Bettis valve actuator was chosen as a sample valve actuator[13]. The time to close the valve will depend on the diameter of the valve. CH·IV consulted

[11] http://www.det-tronics.com/ProductCatalog/GasDetection/Documents/90-1138-10.1-PIRECL.pdf

[12] http://www2.emersonprocess.com/siteadmincenter/PM%20DeltaV%20Documents/Whitepapers/WP_ControlModuleExecution.pdf

[13] http://www.ap.emersonprocess.com/en-US/brands/bettis/products/valve_actuators/actuatorbyApps/Pages/ESD.aspx

with Emerson Automation Solutions to understand typical closing times based on varying diameters. Closing times will depend on project specifics, including the valve selected, the actuator selected, the air pressure in the actuator, the system pressure, process fluid temperature, valve diameter, and system flow rate. A valve package can be assembled to meet closing requirements under 1 second.

However, a hydraulic analysis is typically performed on transfer lines to ensure that the valve will not close at a fast speed against a high pressure and flow which can result in potential damage to piping and equipment. Therefore, to account for the necessary analysis performed during detailed design to finalize valve closing times, a general rule of thumb of 1 second per inch in diameter will be applied to determine a generic closing time.

- Total Time

Based on the above components, a total detection to shutoff time can be estimated as:

5 seconds (gas detector) + 1 second (signal travel to DCS, DCS processing, and signal travel back to valve actuator) + valve diameter in inches (assuming 1 second per inch closure time) = total time

This total time for shutoff will be applied to each line based on the actual diameter of each line.

25.3 Emergency Release Systems

Emergency release systems are common in modern LNG import and export terminals where arms are used to connect to LNG carriers. These systems provide a quick means to protect damage to the marine transfer arms or LNG carriers. The Society of International Gas Tanker and Terminal Operators guidance document "*LNG Emergency Release Systems. Recommendations, Guidelines, and Best Practices*[14]" provides information for users of emergency release systems.

<u>LNG Transfer Arms</u>

Transfer arms are used at LNG facilities to transfer LNG to/from an LNG carrier. Marine transfer arms are robustly designed equipment which articulate from a fixed position to connect to an LNG carrier and allow LNG to be safety transferred to/from an LNG carrier to/from an on-shore LNG facility. Typical vendors for marine transfer arms are FMC[15] and SVT[16].

<u>PERC Valves</u>

[14] http://www.witherbyseamanship.com/lng-emergency-release-systems.html

[15] http://www.fmctechnologies.com/LoadingSystems.aspx

[16] http://www.svt-gmbh.com/en/

Modern LNG facilities equipped with marine transfer arms typically have PERC valves installed on the arms. These valves are essentially a double ball valve configuration with a "PERC collar" installed between the ball valves. The PERC valve system is designed to rapidly disconnect the LNG carrier side from the transfer arm side. The only LNG that is released is the small amount in between the two valves which instantly vaporizes upon release. Figure 25.3 illustrates a PERC Valve Configuration by the manufacturer FMC.

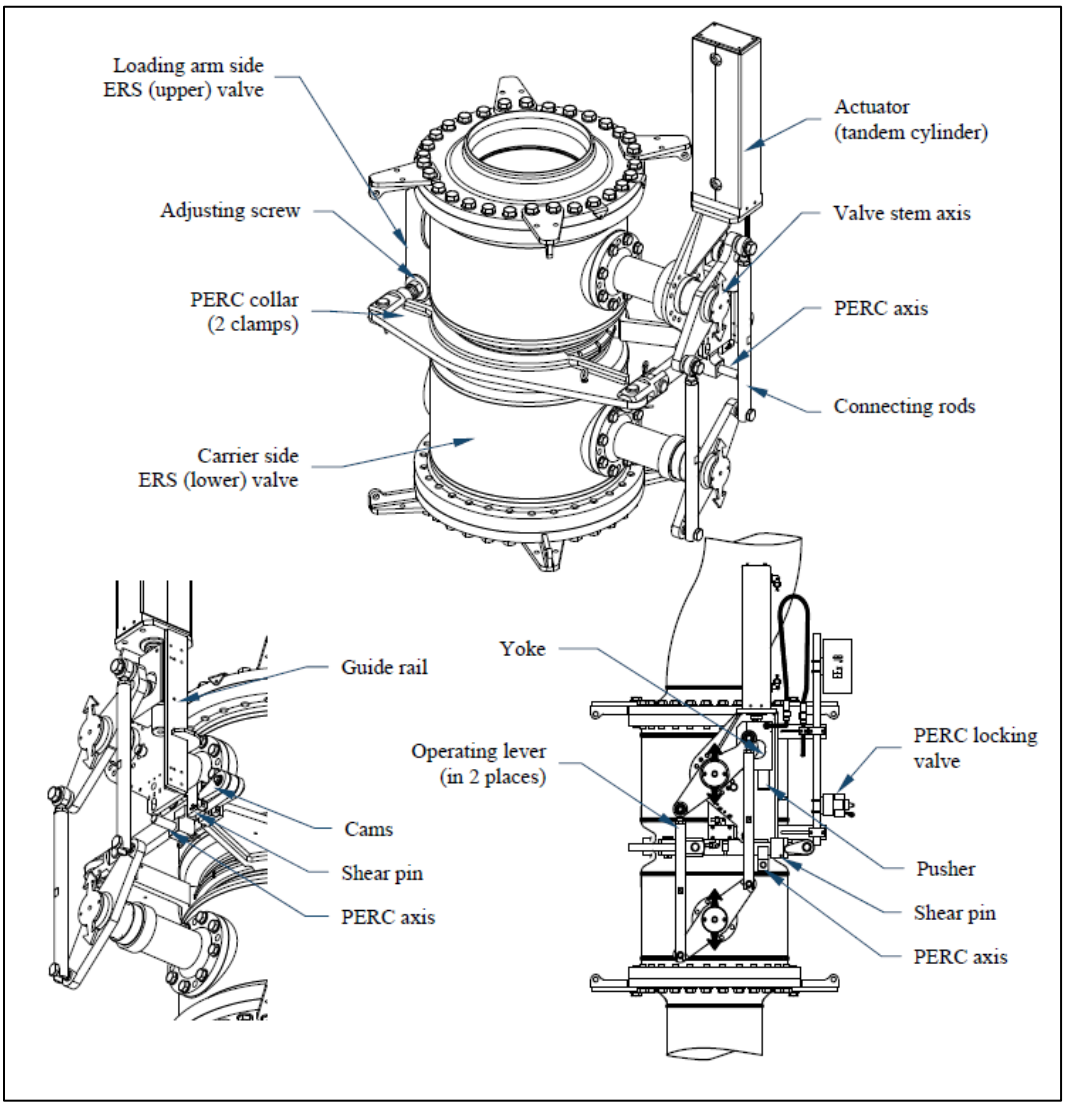

Figure 25.3: FMC PERC Valve Configuration

In conjunction with the marine monitoring system, the PERC valves can be activated based on motion if the marine carrier travels outside of the allowable range for movement. When installed, these valves can provide mitigation against a rupture of a transfer arm. Any scenario which would result in additional forces pulling on a transfer arm (i.e. a ship pull away, large tidal variation, etc.) would result in activation of the PERC valves which provides protection to the transfer arm.

25.4 Breakaway Couplings

Similar to the Emergency Release Systems, breakaway and dry-disconnect couplings provide safe disconnect with minimal LNG release when activated. These are often used on LNG trucking, bunkering, and fuel loading systems.

LNG Transfer Hoses

Typical vendors for LNG transfer hoses include Gutteling[17]. Information provided by Gutteling stated that they have not experienced any loss of containment during a transfer situation. However, they have seen hoses that have become damaged which would need to be replaced.

Gutteling provided information stating that a composite hose does not typically experience failures caused by fatigue as supported by their fatigue testing of their 8" and 10 STS hoses. They have also performed additional fatigue testing on small bore hoses (4 inches and less) to identify maximum limits which illustrated that fatigue issues start to become apparent after 1,000,000 cycles. Maintenance programs which replace hoses as certain intervals can mitigate fatigue at 1,000,000 cycles.

Based on Gutteling's field experience, the most common cause of damage to a hose is almost always handling issues such as:

- Operator errors with hose handling equipment
- Physical damage such as crushing
- Exceeding the bend radius of the hose
- Use of incorrect slings

With proper training and implementation, handling issues can be mitigated. Combined with the low rate of fatigue related failures, hose maintenance programs and training programs can significantly mitigate potential failures of LNG transfer hoses.

Breakaway and Dry Disconnect Couplings

The United States Coast Guard has issued a policy letter titled "Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations" dated February 19, 2015[18]. This policy letter provides guidance to owners and operators of vessels and waterfront facilities intending to conduct LNG fuel transfer operations. The policy letter also identifies the minimum safety and security requirements along with design and procedure requirements for bunkering operations.

[17] www.gutteling.com

[18] https://www.uscg.mil/hq/cg5/cg522/cg5222/docs/CG%20OES%20Policy%20Letter%2002-15%20signature%20with%20Enclosures.pdf

Section 5(d) of the policy letter states that: "*The LNG bunkering manifold should be designed to withstand the external loads during bunkering. The connections at the bunkering station should be of a dry disconnect type equipped with additional safety dry break away coupling/self-sealing quick release. Questions concerning the design of LNG bunkering stations should be directed to the U.S. Coast Guard, Headquarters, Office of Design and Engineering Standards, Commandant (CG-ENG).*" Therefore, developers of bunkering facilities in the United States must include dry disconnect and break away couplings.

Research was performed on several operational bunkering facilities which identified Dixon Valve[19] as a supplier for dry disconnect and break away couplings. The couplings range in size from 1 inch to 6 inch and can be used for fuel bunkering, loading/unloading of tank trucks, rail cars, and ship tankers. The dry disconnect couplings consist of a tank unit or adapter with a spring-loaded poppet and a hose unit or coupler with a valve driven by an internal cam. To couple, the rollers on the coupler are aligned with the notches on the adapter and then rotated to lock the couplings together which creates a seal and opens the internal valves to allow flow. The design seals liquids and gases behind the valve eliminating fugitive emissions and potential spills of cryogenic fluids.

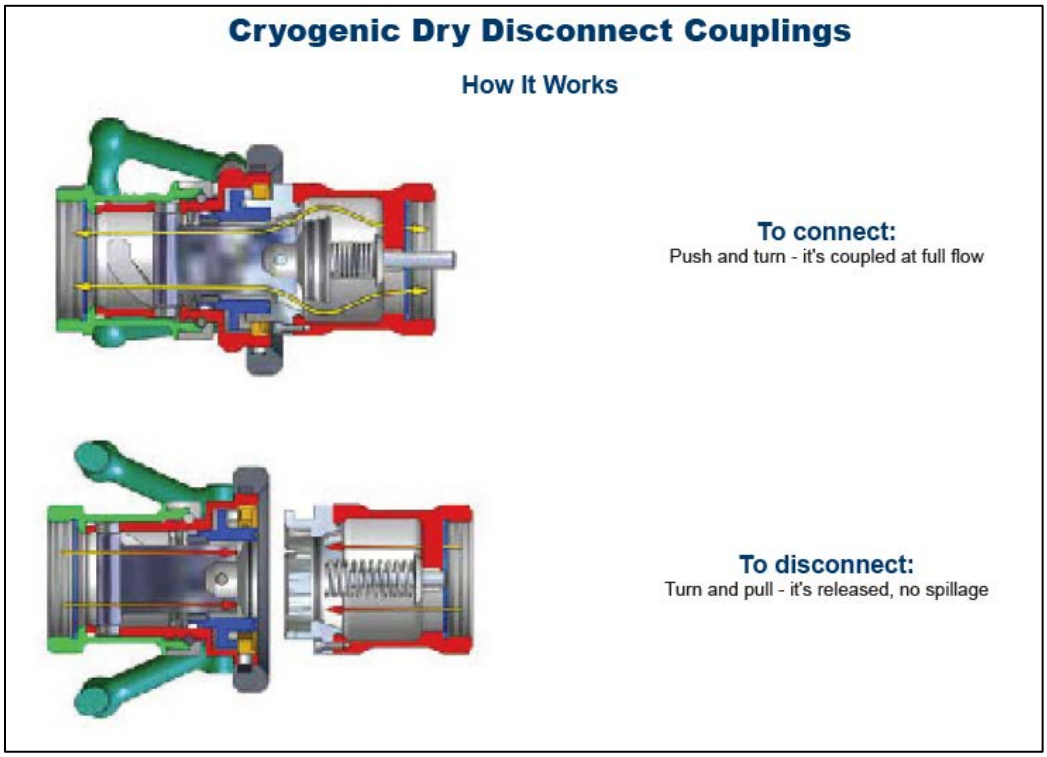

Figure 25.4-1: Cryogenic Dry Disconnect Couplings

Tests were performed by Dixon Valve to determine the volume of spillage upon separation of the disconnect couplings under normal operating conditions. Due to

[19] https://www.dixonvalve.com/

the design of the couplings, the only LNG which is spilled is the wetted film area of the coupling adapter face plates which are connected against each other. The average spill volumes based on the diameter of the hoses is shown in the table below:

Table 25.4.2-1: Spill Volumes on Disconnection

Hose Diameter (inch):	**Socket Diameter:**	**Average Spill Volume:**
1	56 mm	0.1 ml
2	70 mm	0.3 ml
3	119 mm	1.0 ml
4	164 mm	3.5 ml

The tests show that for the largest 4 inch diameter hose, a spill volume of 3.5 ml is expected under normal disconnection, which is negligible and will result in no LNG reaching the ground. For comparison, a teaspoon of liquid is approximately 5 ml.

The disconnect couplings have three external break bolts. When the break bolts reach a specific break force, they break away and the valves rapidly close minimizing releases to the environment. The only LNG that is released is the small amount in between the two valves which instantly vaporizes.

In addition to the dry disconnect couplings, a break-away coupling could be included in the design. These couplings contain two halves of a valve which when pulled allow the valves to rapidly close minimizing releases to the environment. The only LNG that is released during a break-away is the small amount in between the two valves which instantly vaporizes.

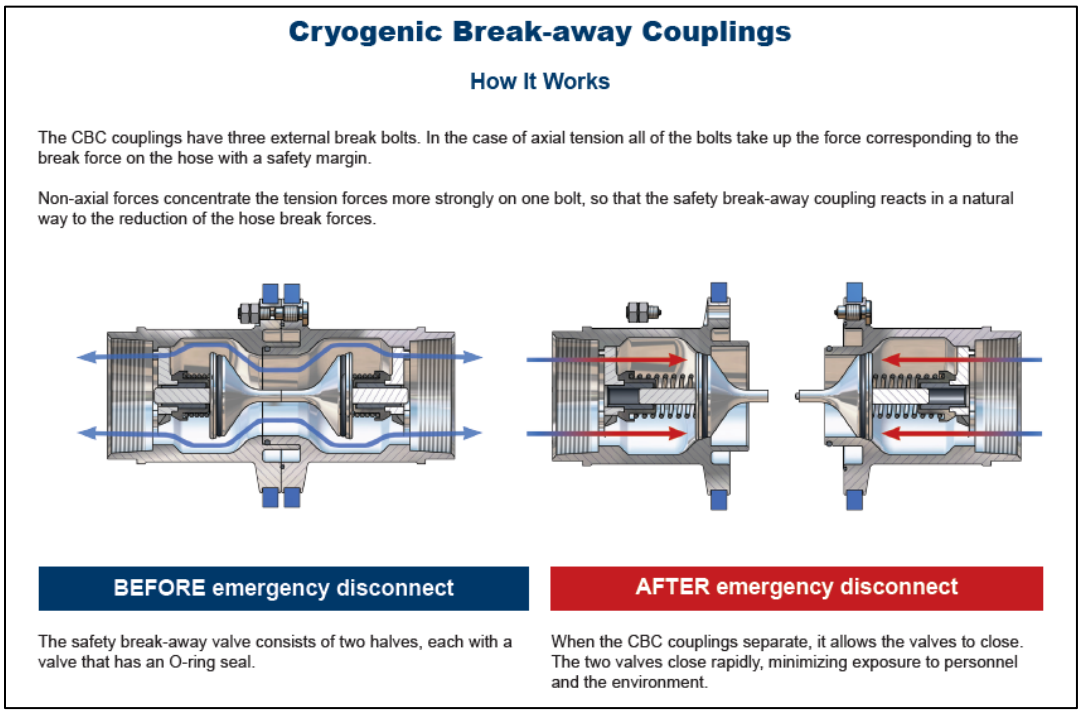

Figure 25.4-2: Cryogenic Break-Away Couplings

The break-away couplings are passive, but can also be designed as a PERC with the inclusion of a nitrogen connection. This system has two couplings joined together for normal operation. A nitrogen connection is added to the break-away coupling which can be controlled remotely. Upon activation, pressurized nitrogen fills the coupling cavity and forces the two pieces apart thereby disconnects the coupling. Similar to the passive break away couplings, this active break-away coupling has only a small amount of liquid in between the two valves which instantly vaporizes upon release.

When installed, these break-away couplings can provide mitigation against a rupture of a transfer hose. Any scenario which would result in additional forces pulling on a transfer hose (i.e. a ship/truck pull away) would result in activation of the break-away coupling which provides protection to the transfer hose. Therefore, an appropriate design spill with the break-away couplings installed for failure scenarios which exert additional axial forces on a transfer hose would be the amount of LNG in between the disconnect valves. Based on consultation with vendors, this volume is extremely small and the resulting vapor dispersion from this volume is negligible.

26 MITIGATED VAPOR DISPERSION MODELING ASSUMPTIONS

The Phast and FLACS models will be used to compare the unmitigated vapor dispersion results with the mitigated results. Scenarios with rainout will be modeled in FLACS whereas scenarios with no rainout fractions will be modeled in Phast. Modeling is only performed on 2 m/s wind speed and 0.03m surface roughness factors.

For the ESD valve mitigation modeling, the only change will be the time duration of the spill. No images are provided for the change in cloud associated with ESD valve mitigation modeling as the overall reduction can be easily quantified. Instead a table is provided to demonstrate the percent reduction in vapor cloud dispersion.

For the vapor fence mitigation modeling, the only change will be the inclusion of vapor fences in the facility geometry. The following sections illustrate the change in vapor cloud travel when vapor fencing is added only. Images are provided to demonstrate the reduction in vapor dispersion distances and also illustrate how the overall cloud shape will change based on the layout of the vapor fences.

Hoses with break-away couplings and transfer arms with PERC valves are not modeled as they result in a negligible release volume.

27 BUNKERING FACILITY MITIGATED VAPOR DISPERSION MODELING

27.1 Jetting and Flashing – Emergency Shutdown

The worst-case scenarios along with the mitigated spill durations are presented in Table 27.1-1 below.

Table 27.1-1 Worst Case Scenarios

Release Scenario #	Location:	Hole Size (inch)	Spill Duration (sec)
B-1	Rundown Line	0.62	8
B-3	Bunkering Line	2.84	12

The results of the modeling along with a percent reduction in vapor dispersion distance due to the mitigated spill durations are included in Table 27.1-2.

Table 27.1-2 LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast		FLACS	
			Distance to ½ LFL (ft)	% Reduction	Distance to ½ LFL (ft)	% Reduction
B-1	2	0.03	201.7	42%	-	-
B-3	2	0.03	-	-	1,000.65	55%

As shown in the table above, accounting for active emergency shutdown systems can have a significant decrease on the overall duration of a design spill and subsequent vapor dispersion exclusion zone. This mitigation feature showed a reduction in vapor dispersion exclusion zones of:

- 41% for the rundown line spill, and
- 55% for the bunkering line spill.

27.2 Jetting and Flashing – Vapor Fences

The worst-case scenarios to be modeled with vapor fences are presented in Table 27.2 below.

Table 27.2 Worst Case Scenarios

Release Scenario #	Location:	Hole Size (in)
B-3	Bunkering Line	2.84

The following figure shows the initial results of scenario B-3 unmitigated:

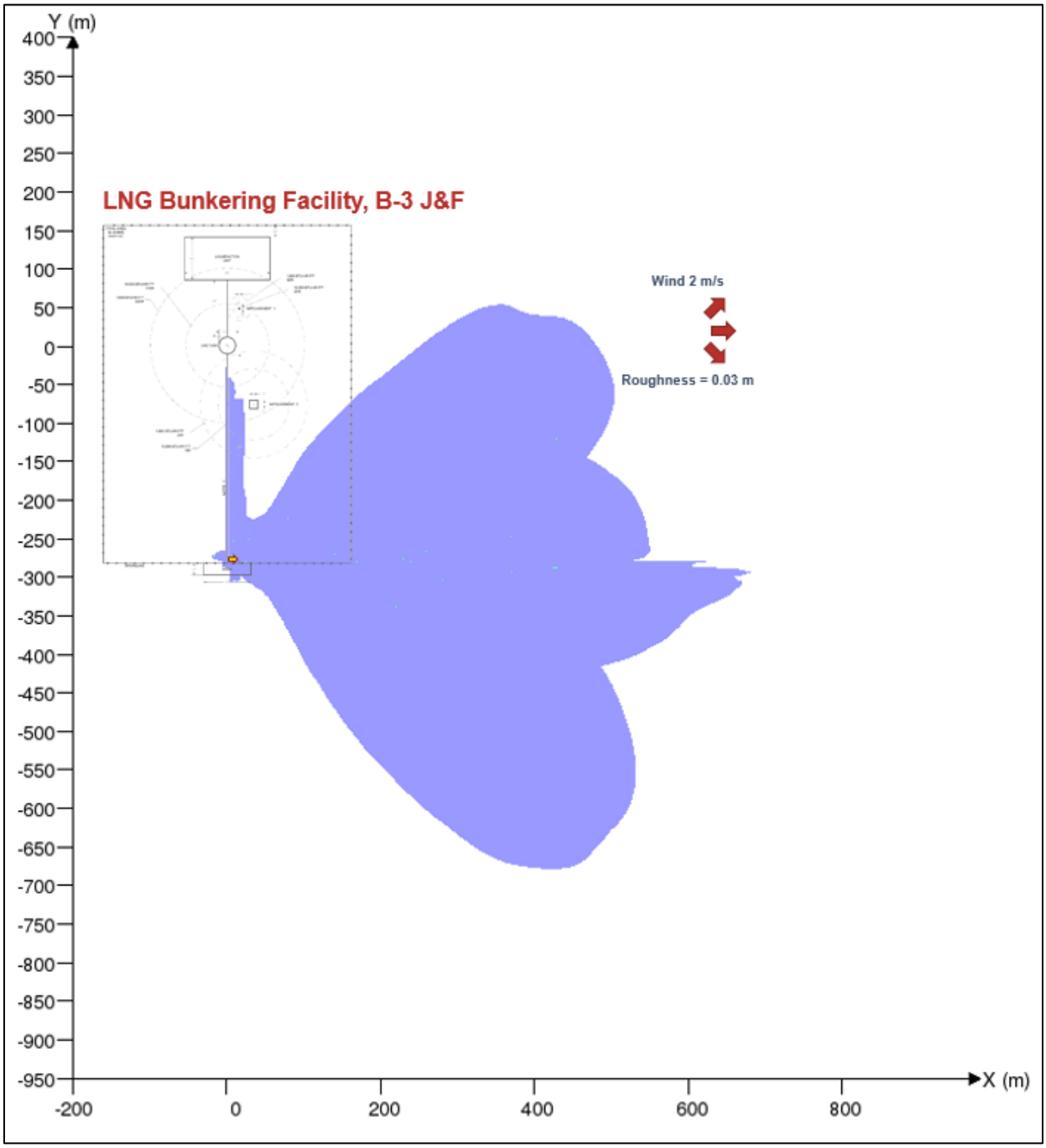

Figure 27.2-1: Bunkering Line Unmitigated

A 20-foot-tall solid vapor fence has been placed along the East perimeter property line. The results of the jetting and flashing vapor dispersion modeling with the inclusion of the vapor fence is illustrated in the following figure:

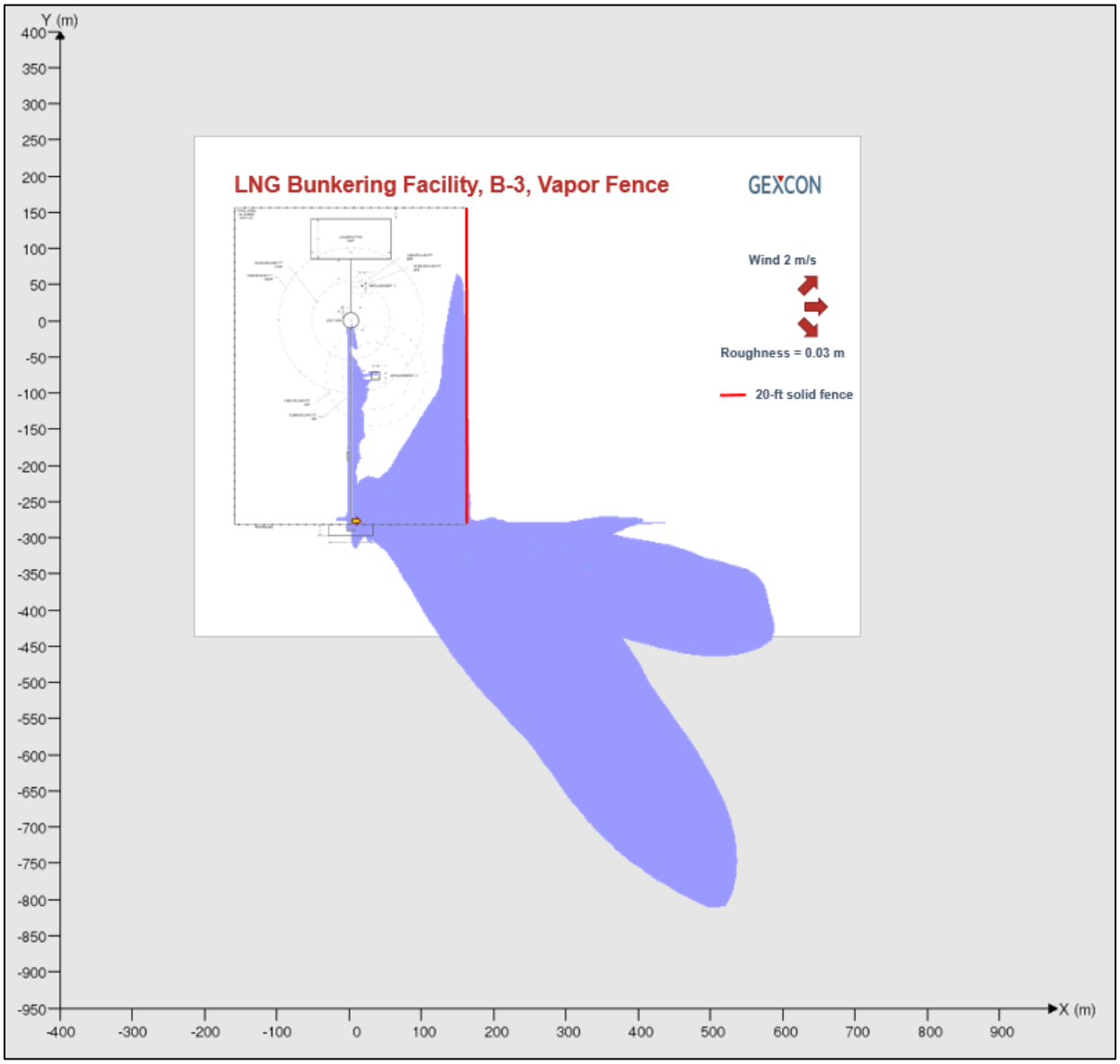

Figure 27.2-2: Bunkering Line Mitigated

As detailed in the figures above, the addition of vapor fences provides an obstruction to contain LNG vapors and can have a significant impact on the vapor dispersion exclusion zone. The initial unmitigated release showed significant cloud travel to the East across the East property line. When the vapor fence was added, it provided vapor holdup and did not allow vapors to escape as significantly to the East. However, as the mass flow rate from the release remained unchanged, the amount of LNG spilled during the release remained unchanged. As such, additional vapors were therefore restricted to the site property and the vapor cloud was channeled along the vapor fence to the North and the South. In this scenario, the placement of the vapor fence allowed the overall footprint of the vapor dispersion exclusion zone to change based on the facility geometry resulting in a decrease in the vapor

dispersion exclusion zone to the East across the facility property line, but an increase in the vapor dispersion exclusion zone to the North inside the facility property line and an increase in the vapor dispersion exclusion zone to the South across the waterway.

28 EXPORT FACILITY MITIGATED VAPOR DISPERSION MODELING

28.1 Jetting and Flashing – Emergency Shutdown

The worst-case scenarios along with the mitigated spill durations are presented in Table 28.1-1 below.

Table 28.1-1 Worst Case Scenarios

Release Scenario #	Location:	Hole Size (in)	Spill Duration (sec)
E-1	Rundown Line	5.3	22
E-6	Rundown Header	9.3	34
E-11	Marine Loading Line at Storage Tank	12	42
E-16	Marine Loading Line at Jetty	12	42
E-21	Truck Loading Line	1.48	10

The results of the modeling along with a percent reduction in vapor dispersion distance due to the mitigated spill durations are included in Table 28.1-2.

Table 28.1-2 LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast		FLACS (No Geometry)	
			Distance to ½ LFL (ft)	% Reduction	Distance to ½ LFL (ft)	% Reduction
E-1	2	0.03	-	-	1,066.27	52%
E-6	2	0.03	-	-	1,295.93	45%
E-11	2	0.03	-	-	3,576.12	53%
E-16	2	0.03	-	-	3,248.03	64%
E-21	2	0.03	365.1	48%	-	-

As detailed in the table above, accounting for active emergency shutdown systems can have a significant decrease on the overall duration of a design spill and subsequent vapor dispersion exclusion zone. This mitigation feature showed a reduction in vapor dispersion exclusion zones of:

- 52% for the rundown line spill,
- 45% for the rundown line header spill,

- 53% for the marine loading line at the LNG storage tank,
- 64% for the marine loading line at the jetting, and
- 48% for the truck loading line spill.

28.2 Jetting and Flashing – Vapor Fences

The worst-case scenarios to be modeled with vapor fences are presented in Table 28.2 below.

Table 28.2 Worst Case Scenarios

Release Scenario #	Location:	Hole Size (in)
E-6	Rundown Header	9.3
E-11	Marine Loading Line at Storage Tank	12

Rundown Header:

The following figures shows the initial results of scenarios E-6 unmitigated:

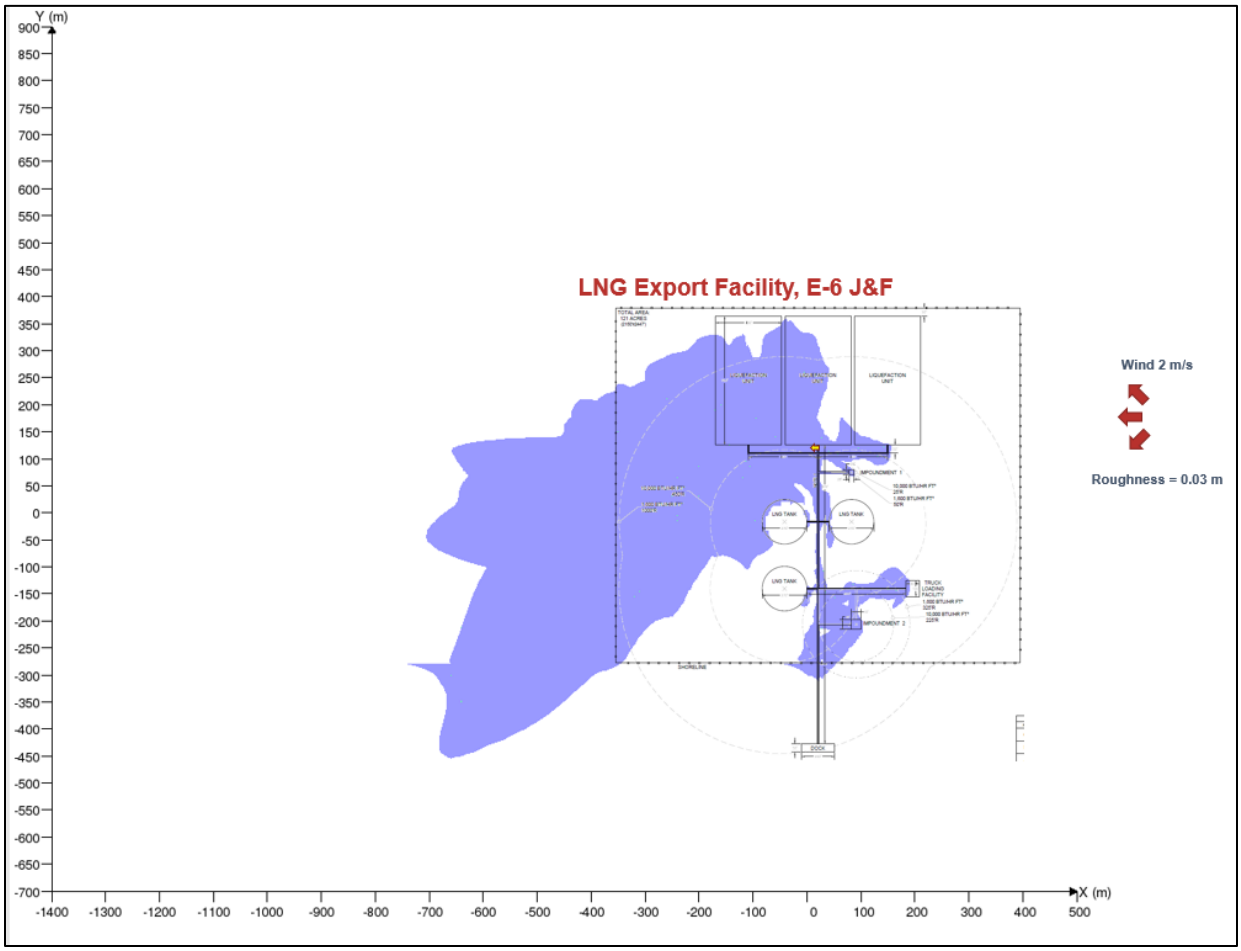

Figure 28.2-1: Rundown Header Unmitigated (West)

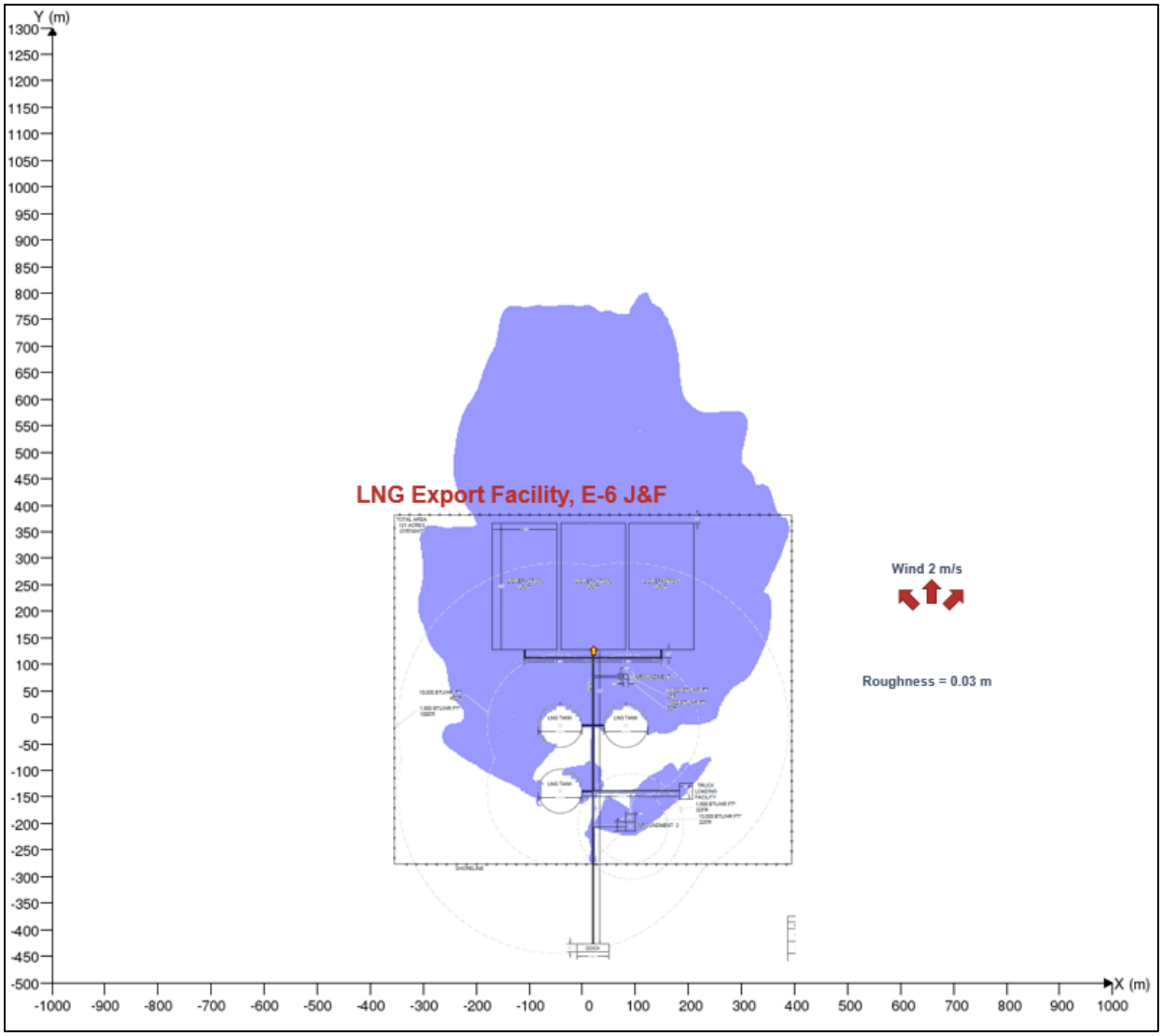

Figure 28.2-2: Rundown Header Unmitigated (North)

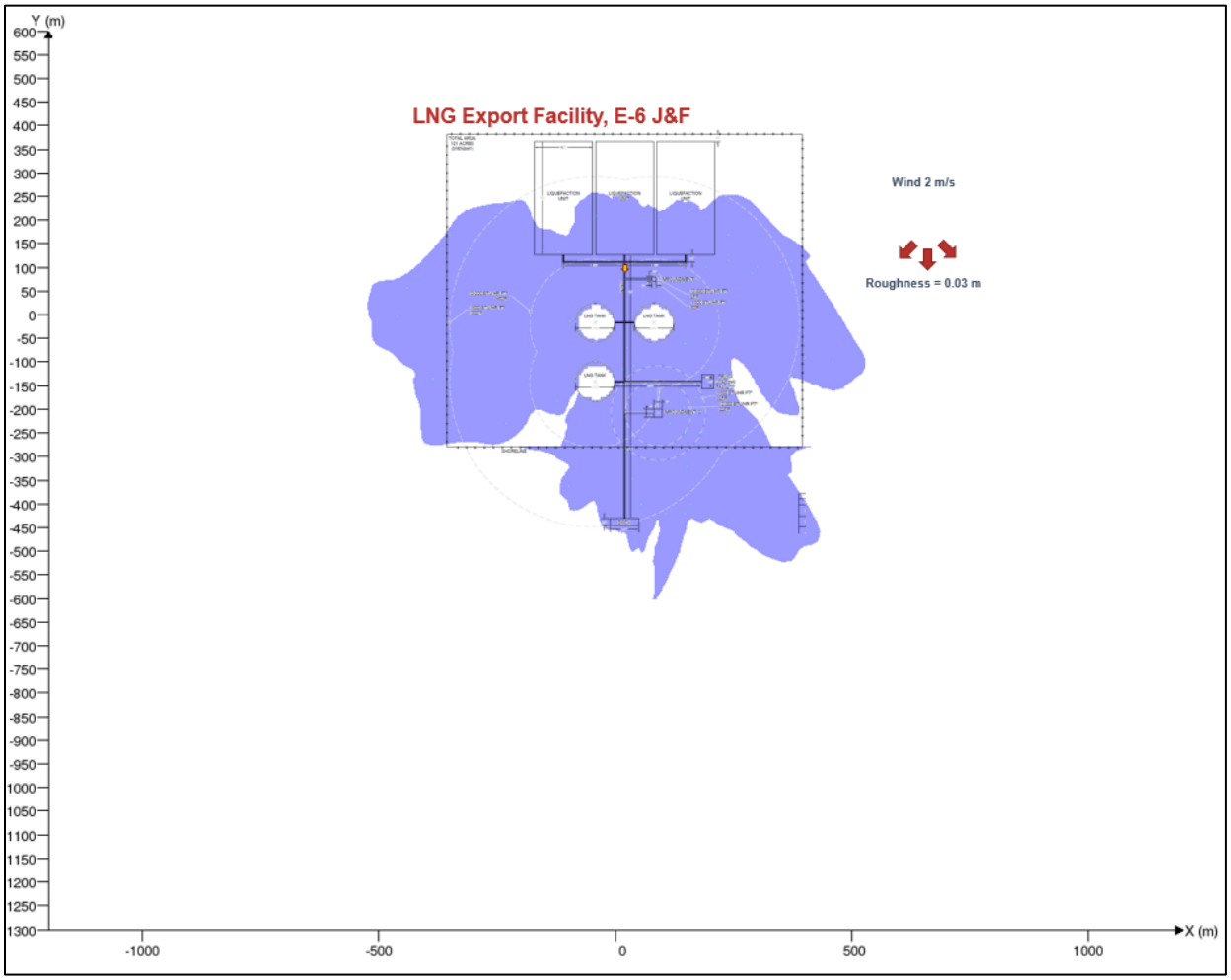

Figure 28.2-3: Rundown Header Unmitigated (South)

A 20-foot-tall solid vapor fence has been placed along the East, North, and West perimeter property line. The results of the jetting and flashing vapor dispersion modeling with the inclusion of the vapor fence is illustrated in the following figures:

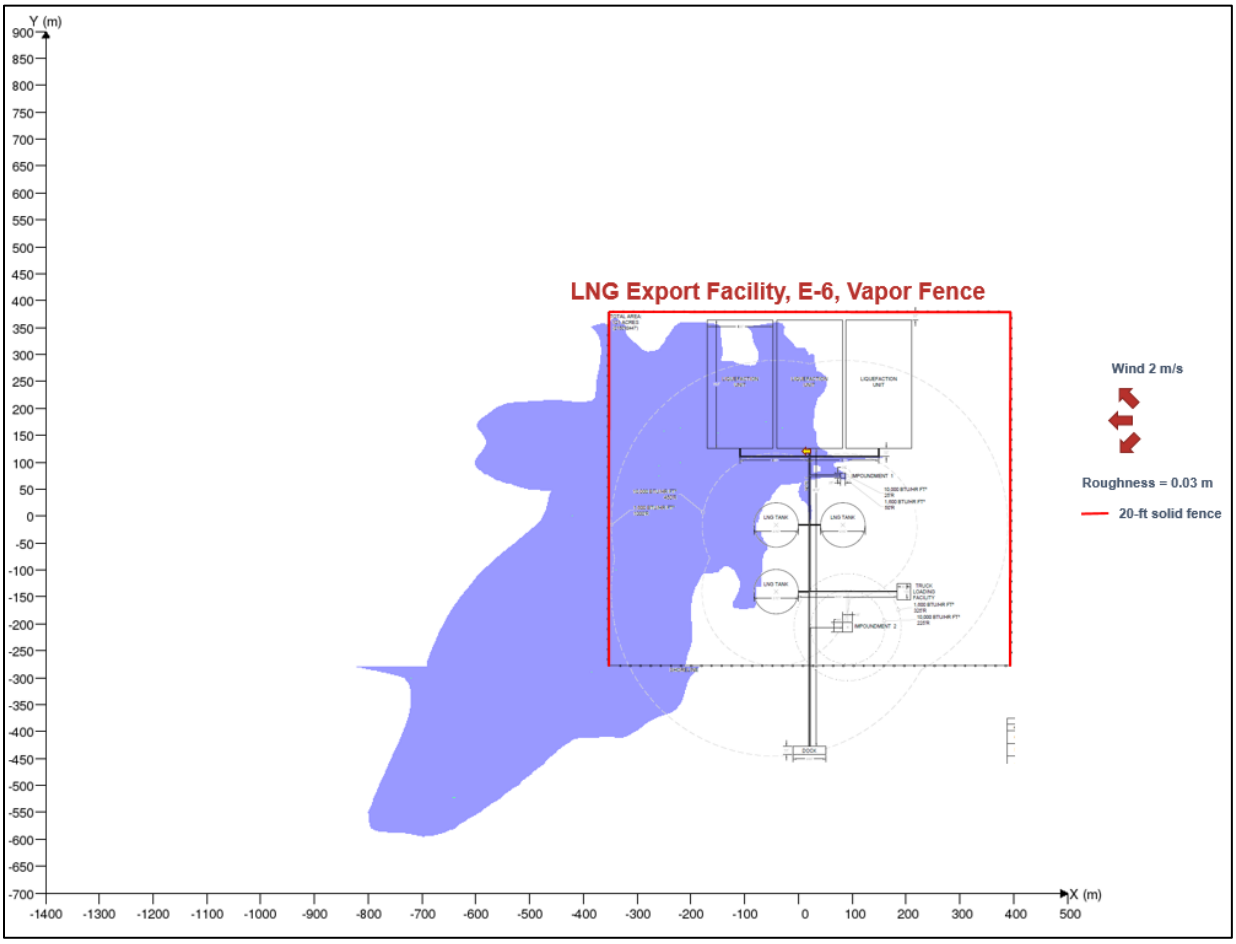

Figure 28.2-4: Rundown Header Mitigated (West)

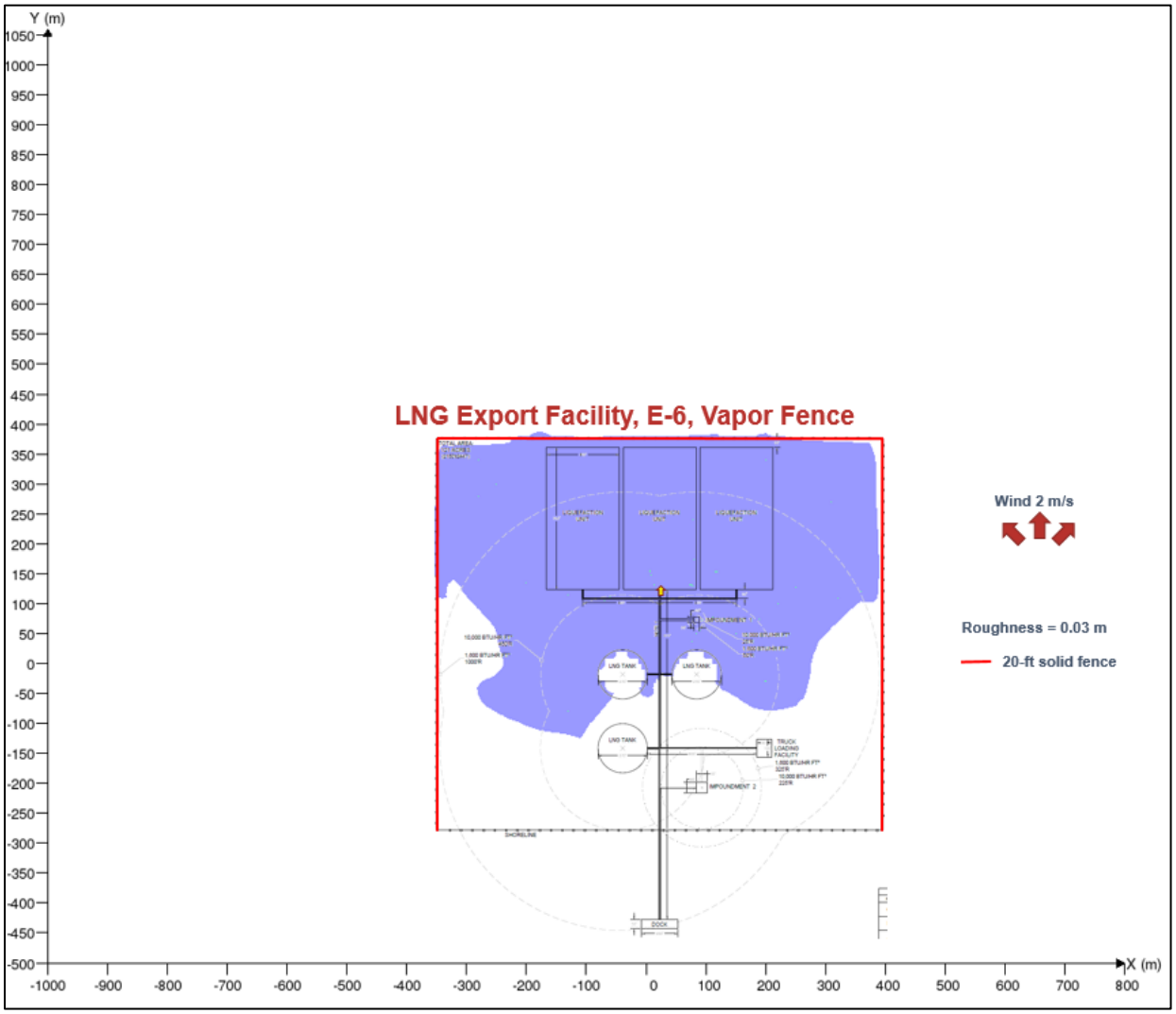

Figure 28.2-5: Rundown Header Mitigated (North)

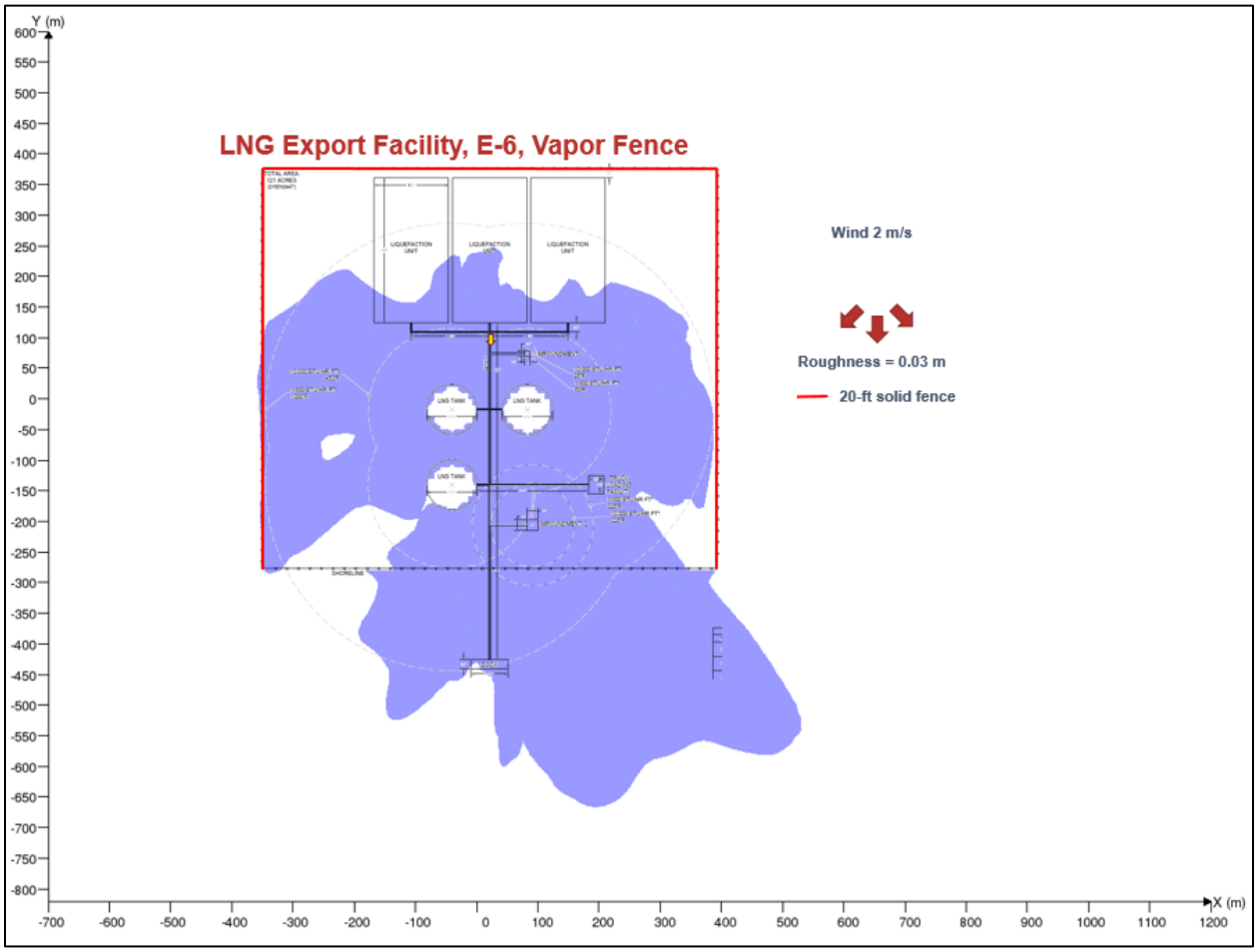

Figure 28.2-6: Rundown Header Mitigated (South)

As detailed in the figures above, the addition of vapor fences provides an obstruction to contain LNG vapors and can have a significant impact on the vapor dispersion exclusion zone.

The initial unmitigated release showed significant cloud travel across all property lines. When the vapor fence was added, it provided vapor holdup and had an impact on the overall shape of the vapor dispersion exclusion zone. However, as the mass flow rate from the release remained unchanged, the amount of LNG spilled during the release remained unchanged.

The release to the West was unobstructed until it hit the vapor fence. As such, while the vapor fence did provide an obstruction, the large mass of the cloud accumulated at the base of the vapor fence and eventually overflowed the vapor fence. To fully mitigate this scenario, either the height of the vapor fence would need to be increased or an additional vapor fence would be needed closer to the source to reduce the momentum of the release.

The release to the North encountered obstructions from the liquefaction train causing mixing and reducing momentum. As such, the placement of the vapor fence kept all vapors from the release inside the property line. The vapor fences resulted in an approximate 50% reduction in vapor dispersion exclusion zone distance.

The release to the South originally flared out and crossed both the East and West property lines. As the momentum and wind direction associated with the release was Southerly, the vapor fences on the East and West side property line were successful in channeling the flaring out and pushing that vapor along the vapor fence to the South to be dispersed across water.

Marine Transfer Line:

The following figures shows the initial results of scenarios E-11 unmitigated:

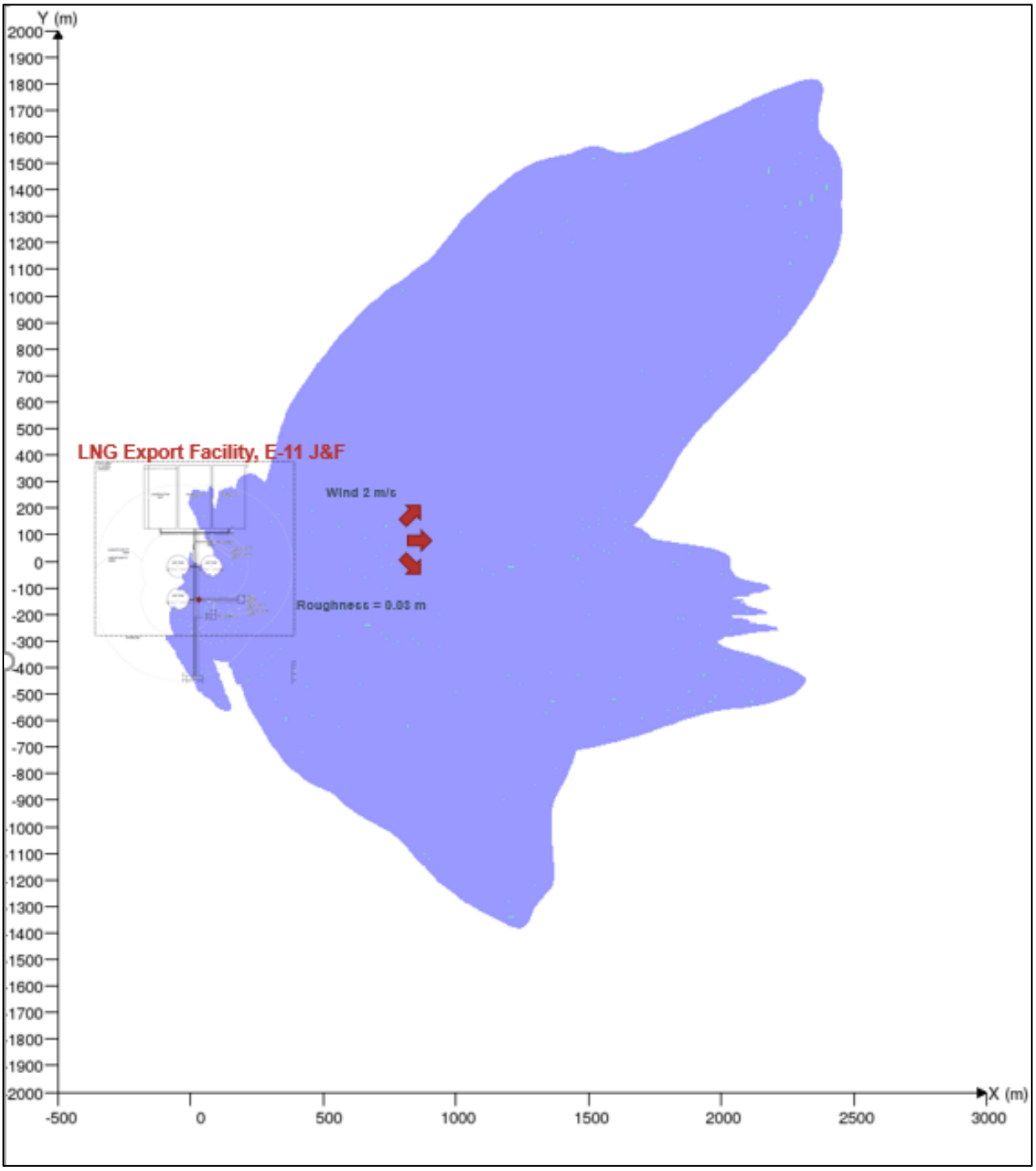

Figure 28.2-7: Marine Line Unmitigated (East)

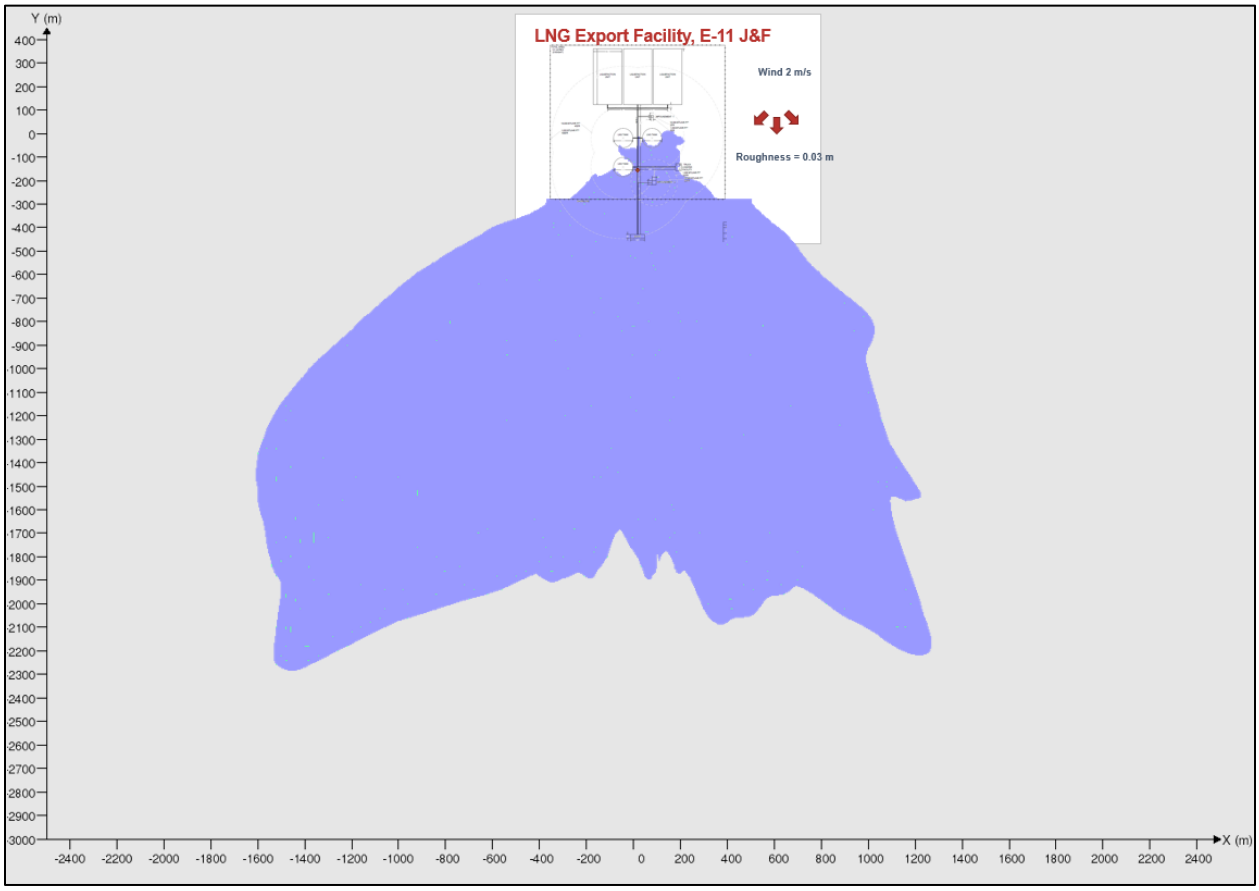

Figure 28.2-8: Marine Line Unmitigated (South)

A 20-foot-tall solid vapor fence has been placed along the East, North, and West perimeter property line. The results of the jetting and flashing vapor dispersion modeling with the inclusion of the vapor fence is illustrated in the following figures:

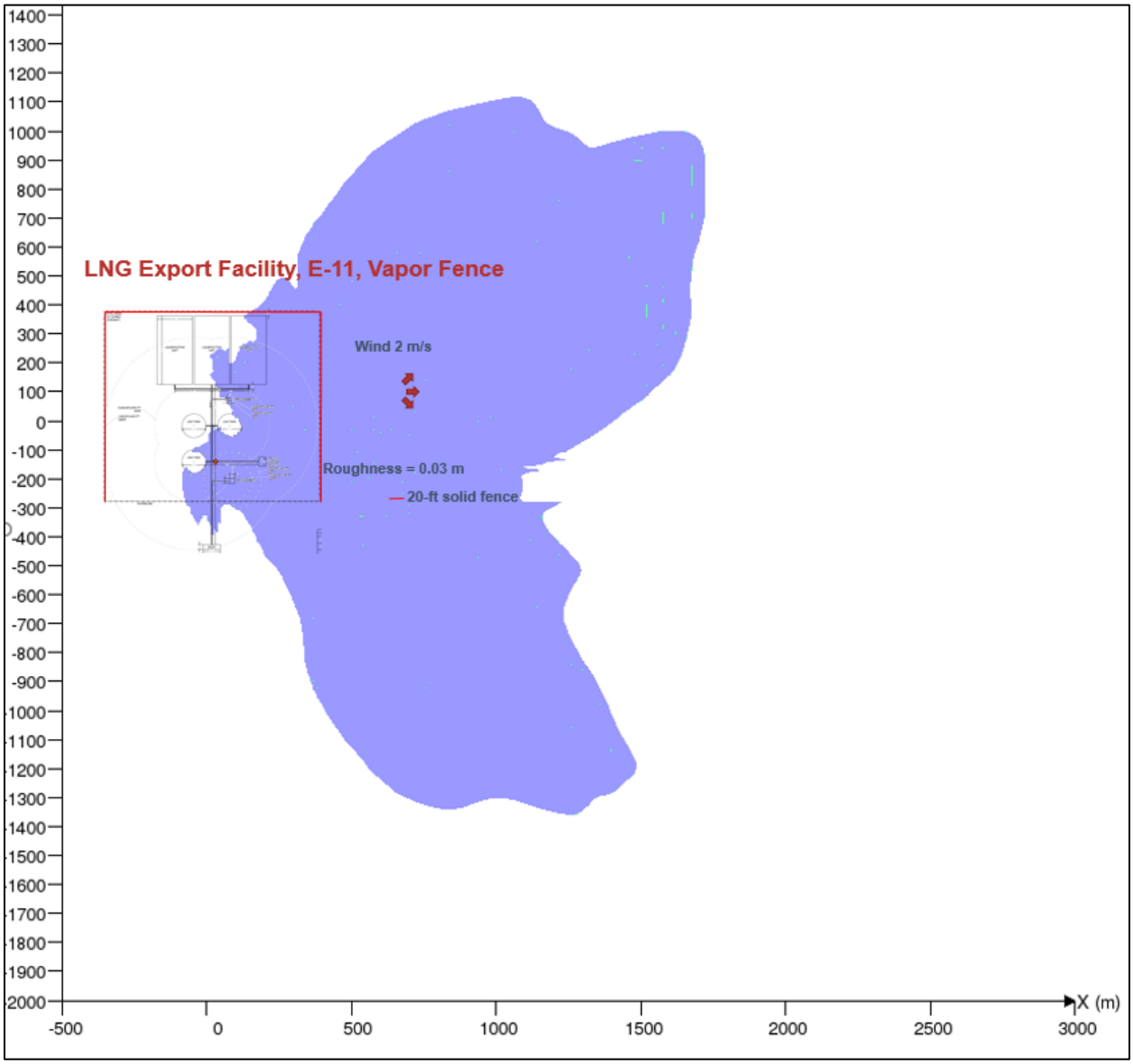

Figure 28.2-9: Marine Transfer Mitigated (East)

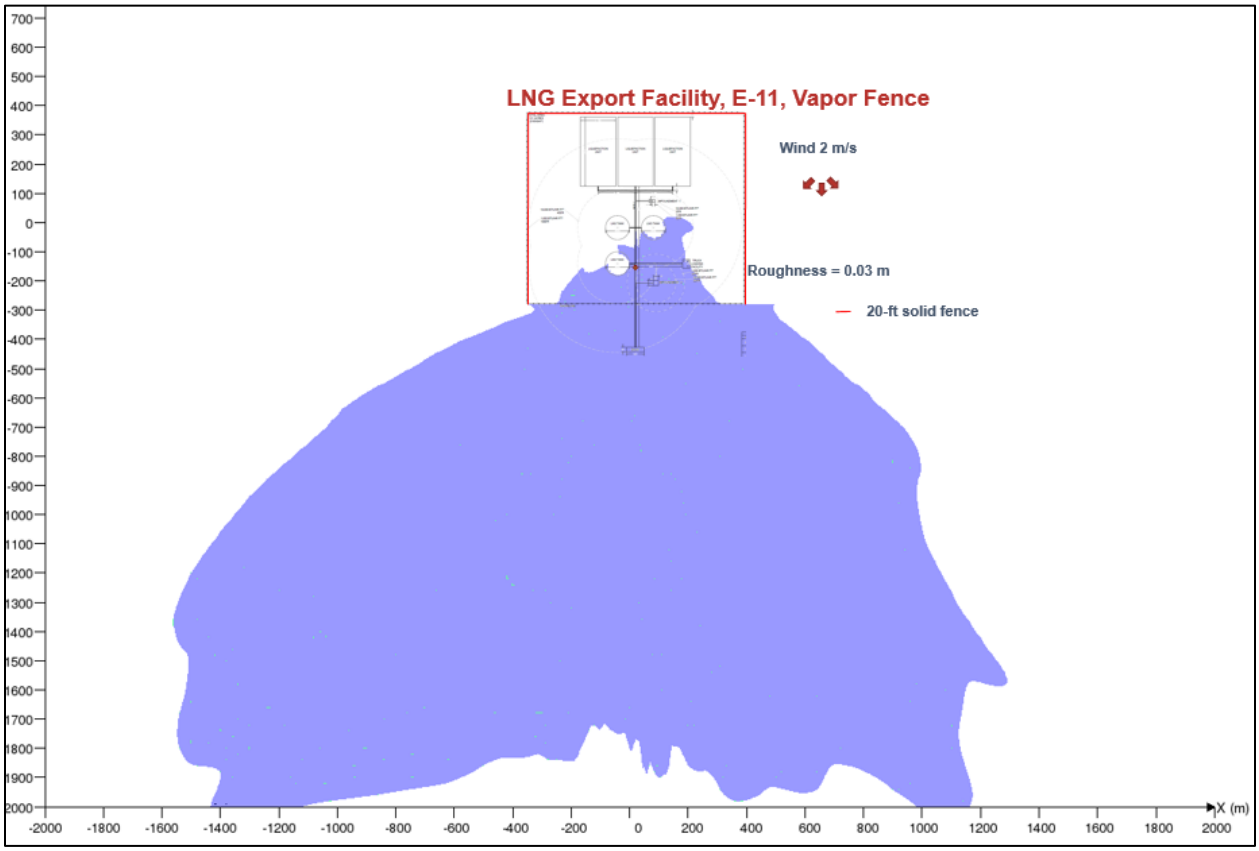

Figure 28.2-10: Marine Transfer Mitigated (South)

As detailed in the figures above, the addition of passive vapor fences provides an obstruction to contain LNG vapors and can have a significant impact on the vapor dispersion exclusion zone.

The initial unmitigated release showed significant cloud travel across all property lines. When the vapor fence was added, it provided vapor holdup and had an impact on the overall shape of the vapor dispersion exclusion zone. However, as the mass flow rate from the release remained unchanged, the amount of LNG spilled during the release remained unchanged.

The release to the East was unobstructed until it hit the vapor fence. As such, while the vapor fence did provide an obstruction, the large mass of the cloud accumulated at the base of the vapor fence and eventually overflowed the vapor fence. To fully mitigate this scenario, either the height of the vapor fence would need to be increased or an additional vapor fence would be needed closer to the source to reduce the momentum of the release. The vapor fences resulted in an approximate 30% reduction in vapor dispersion exclusion zone distance.

The release to the South originally flared out and crossed both the East and West property lines. As the momentum and wind direction associated with the release was Southerly, the vapor fences on the East and West side property line were

successful in channeling the flaring out and pushing that vapor along the vapor fence to the South to be dispersed across water.

29 FUEL LOADING FACILITY MITIGATED VAPOR DISPERSION MODELING

29.1 Jetting and Flashing – Emergency Shutdown

The worst-case scenarios along with the mitigated spill durations are presented in Table 29.1-1 below.

Table 29.1-1: Worst Case Scenarios

Release Scenario #	Location:	Hole Size (in)	Spill Duration (sec)
F-1	Rundown Line	0.62	8
F-3	Fuel Loading Line	1.48	10

The results of the modeling along with a percent reduction in vapor dispersion distance due to the mitigated spill durations are included in Table 29.1-2.

Table 29.1-2: LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast		FLACS	
			Distance to ½ LFL (ft)	% Reduction	Distance to ½ LFL (ft)	% Reduction
F-1	2	0.03	201.7	42%	-	-
F-3	2	0.03	365.1	48%	-	-

29.2 Jetting and Flashing – Vapor Fences

The worst-case scenarios to be modeled with vapor fences are presented in Table 29.2 below.

Table 29.2: Worst Case Scenarios

Release Scenario #	Location:	Hole Size (in)
F-3	Fuel Loading Line	1.48

The following figures shows the initial results of scenarios F-3 unmitigated:

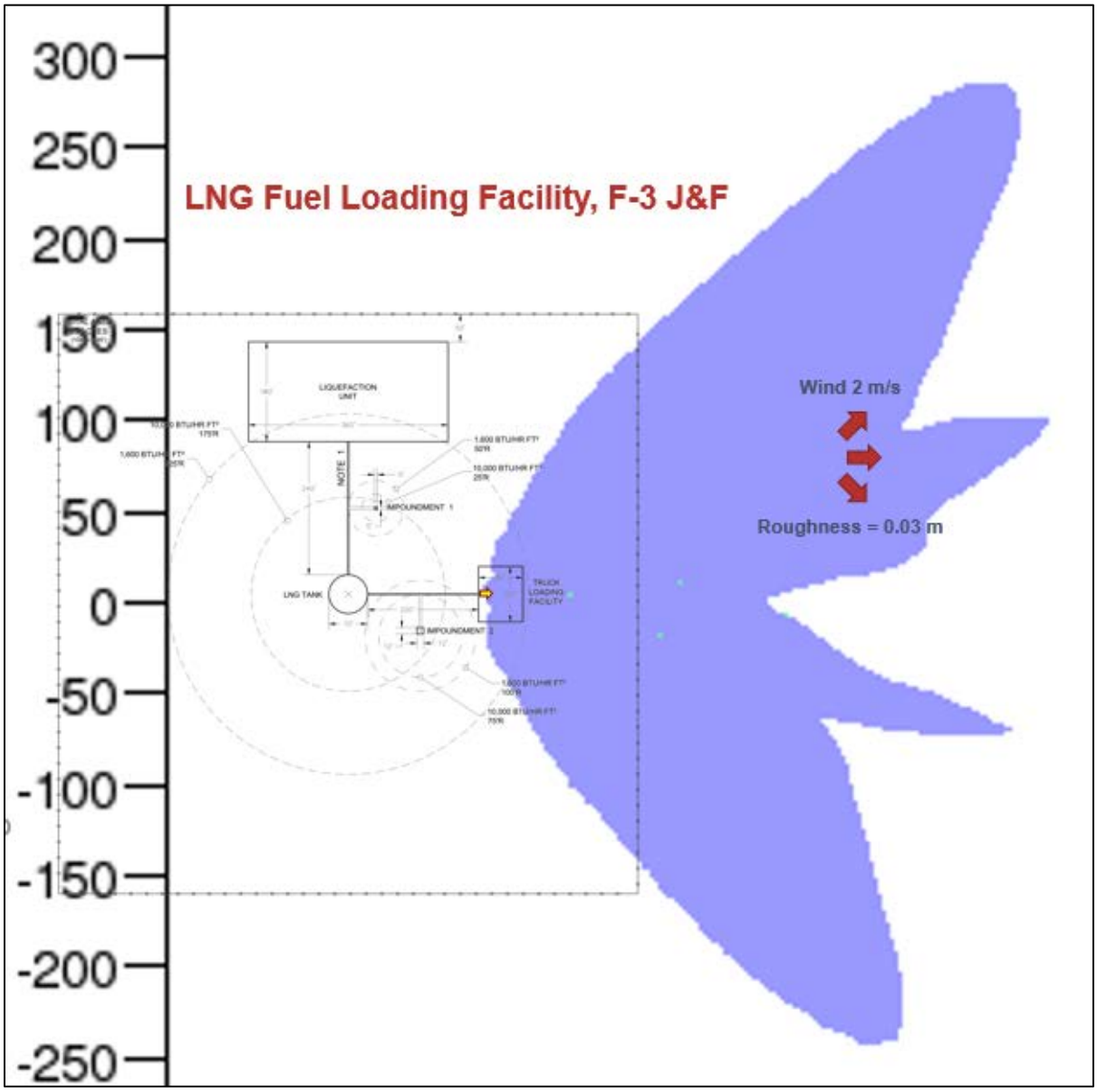

Figure 29.2-1: Fuel Loading Line Unmitigated (East)

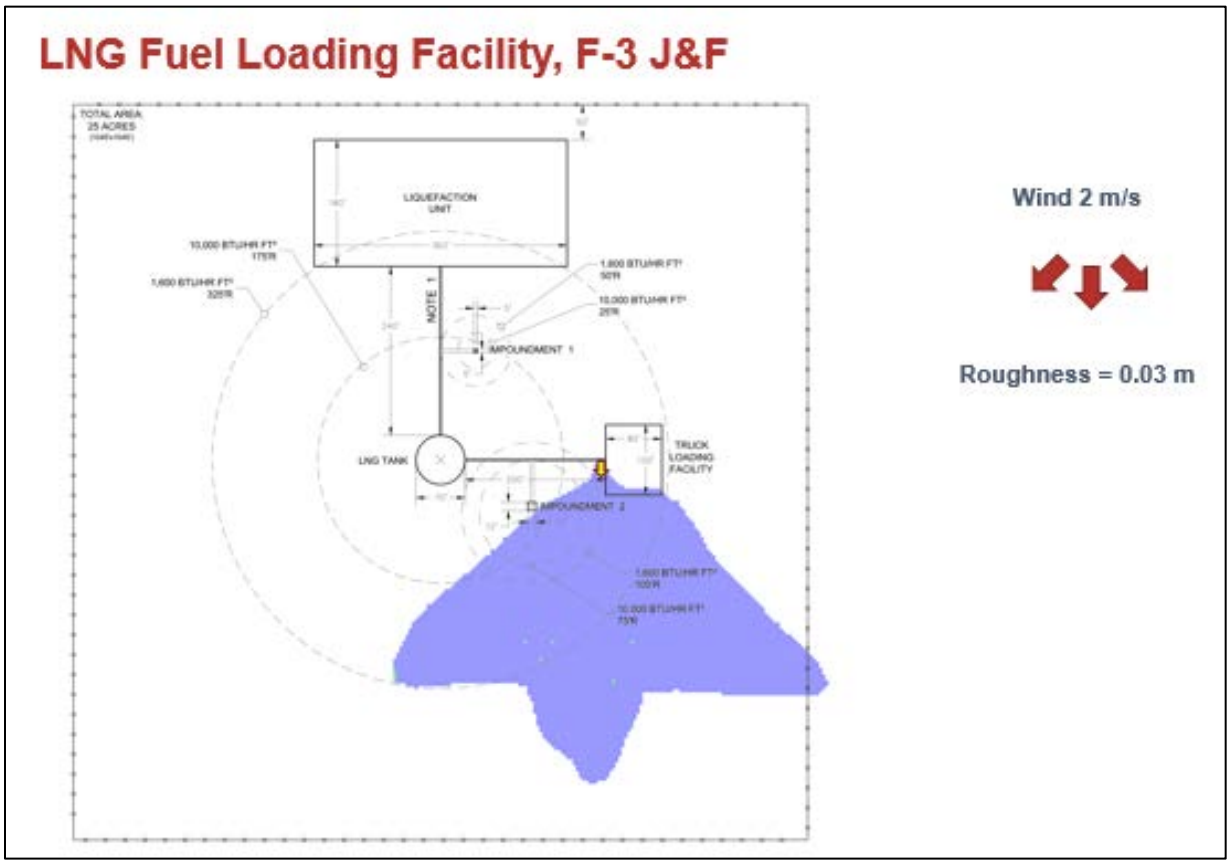

Figure 29.2-2: Fuel Loading Line Unmitigated (South)

A 20-foot-tall solid vapor fence has been placed along the East property lines which slightly wraps around the North and South property lines. The results of the jetting and flashing vapor dispersion modeling with the inclusion of the vapor fence is illustrated in the following figures:

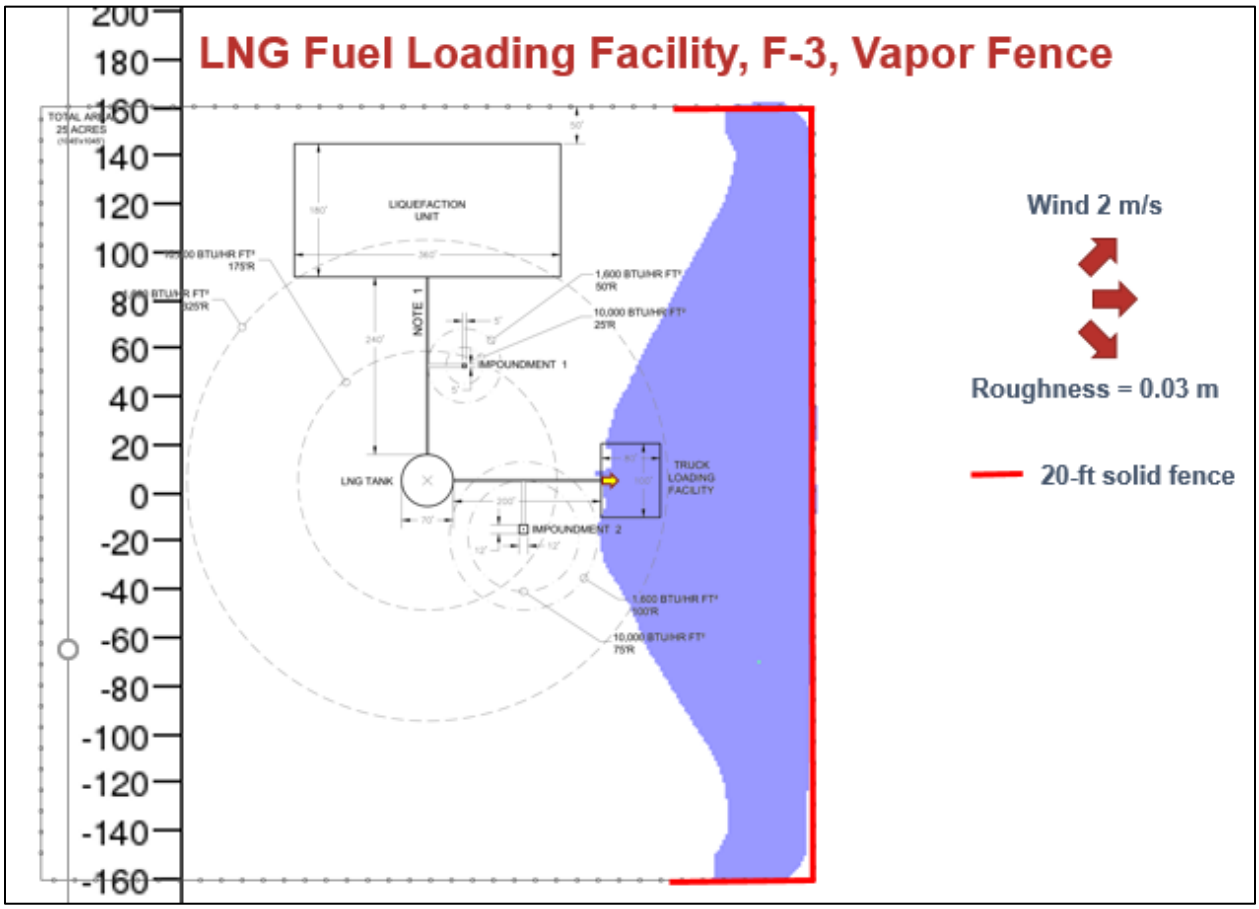

Figure 29.2-3: Fuel Loading Line Mitigated (East)

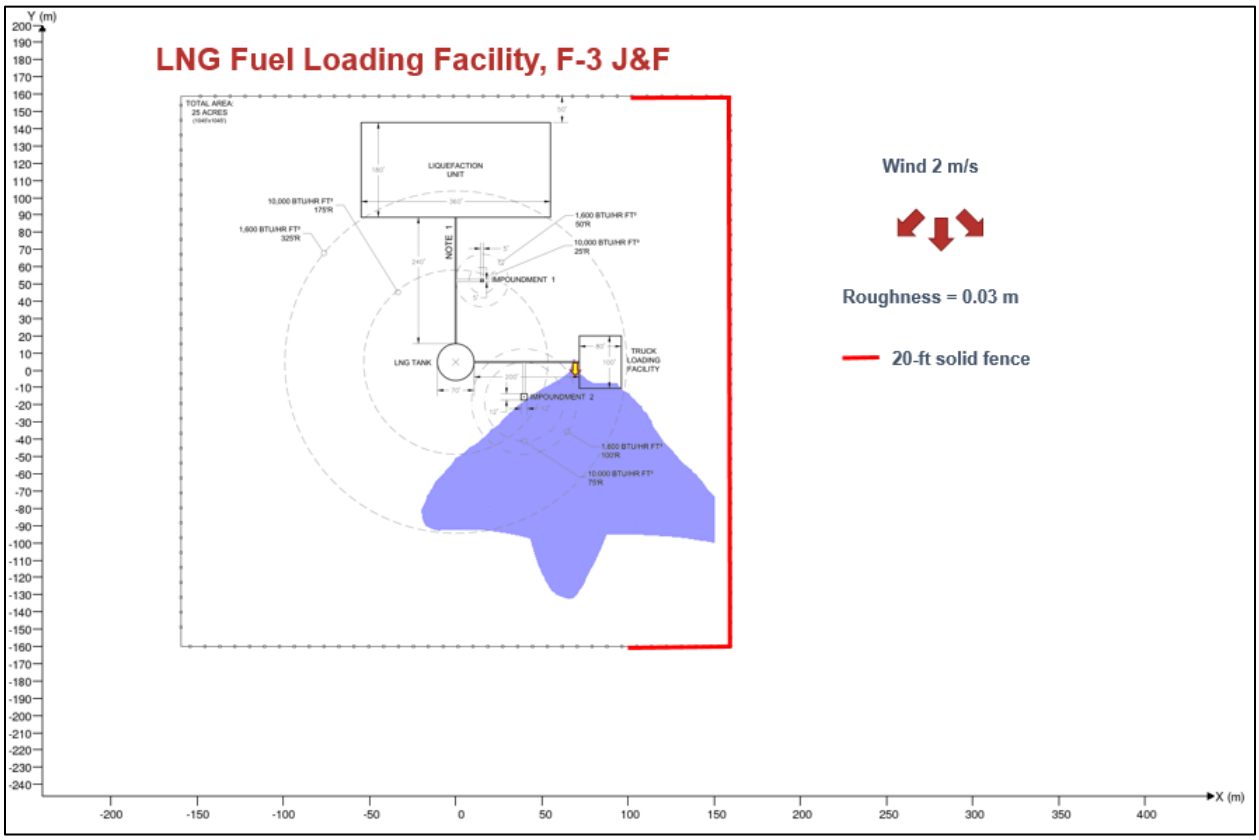

Figure 29.2-4: Fuel Loading Line Mitigated (South)

As detailed in the figures above, the addition of passive vapor fences provides an obstruction to contain LNG vapors and can have a significant impact on the vapor dispersion exclusion zone.

The initial unmitigated release showed significant cloud travel across the East property line. When the vapor fence was added, it provided vapor holdup and had an impact on the overall shape of the vapor dispersion exclusion zone. However, as the mass flow rate from the release remained unchanged, the amount of LNG spilled during the release remained unchanged.

The release to the East was unobstructed until it hit the vapor fence. However, due to the height of the fence, the large mass of the cloud accumulated at the base of the vapor fence and was channeled North and South along the fence remaining inside the property line. The vapor fences resulted in an approximate 60% decrease in vapor dispersion exclusion zone distance.

The release to the South originally flared out and crossed the East property line. The vapor fence on the East property line was successful in keeping the flaring inside the property line.

30 PEAKSHAVER FACILITY MITIGATED VAPOR DISPERSION MODELING

30.1 Jetting and Flashing – Emergency Shutdown

The worst-case scenarios along with the mitigated spill durations are presented in Table 30.1-1 below.

Table 30.1-1: Worst Case Scenarios

Release Scenario #	Location:	Hole Size (in)	Spill Duration (sec)
P-1	Rundown Line	1.09	10
P-5	LP Sendout Line	5	16
P-10	HP Sendout Line	3.3	16
P-15	Truck Loading Line	1.48	10

The results of the modeling along with a percent reduction in vapor dispersion distance due to the mitigated spill durations are included in Table 30.1-2.

Table 30.1-2: LNG Jetting and Flashing Results

Release Scenario #	Wind Speed (m/s)	Surface Roughness Factor (m)	Phast		FLACS	
			Distance to ½ LFL (ft)	% Reduction	Distance to ½ LFL (ft)	% Reduction
P-1	2	0.03	310.12	45%	-	-
P-5	2	0.03	-	-	918.64	52%
P-10	2	0.03	1,067.8	60%		
P-15	2	0.03	360.8	48%		

30.2 Jetting and Flashing – Vapor Fences

The worst-case scenarios to be modeled with vapor fences are presented in Table 30.2 below.

Table 30.2 Worst Case Scenarios

Release Scenario #	Location:	Hole Size (in)
P-5	LP Sendout Line	5
P-10	HP Sendout Line	3.3

LP Sendout Line:

The following figures shows the initial results of scenarios P-5 unmitigated:

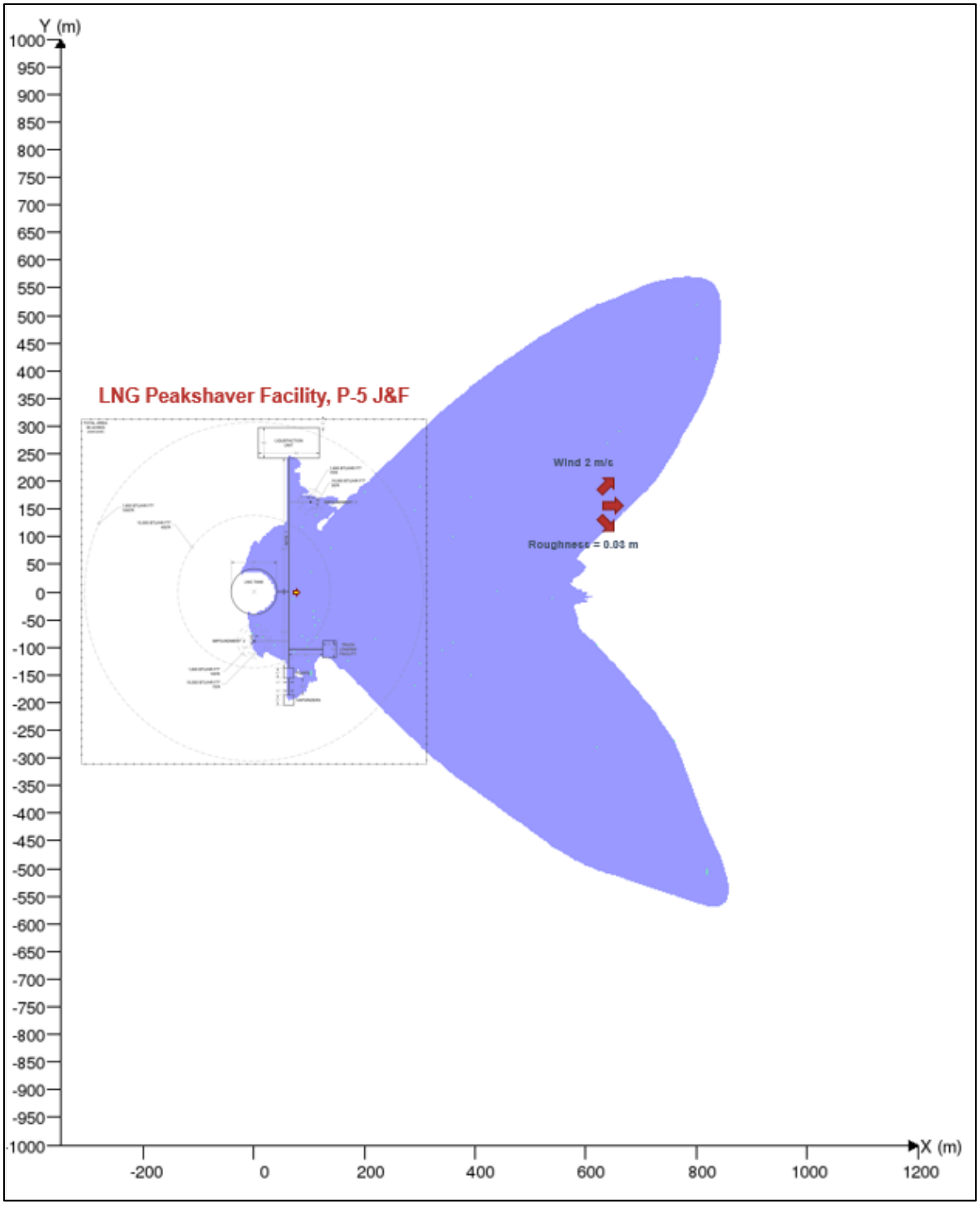

Figure 30.2-1: LP Sendout Line Unmitigated (East)

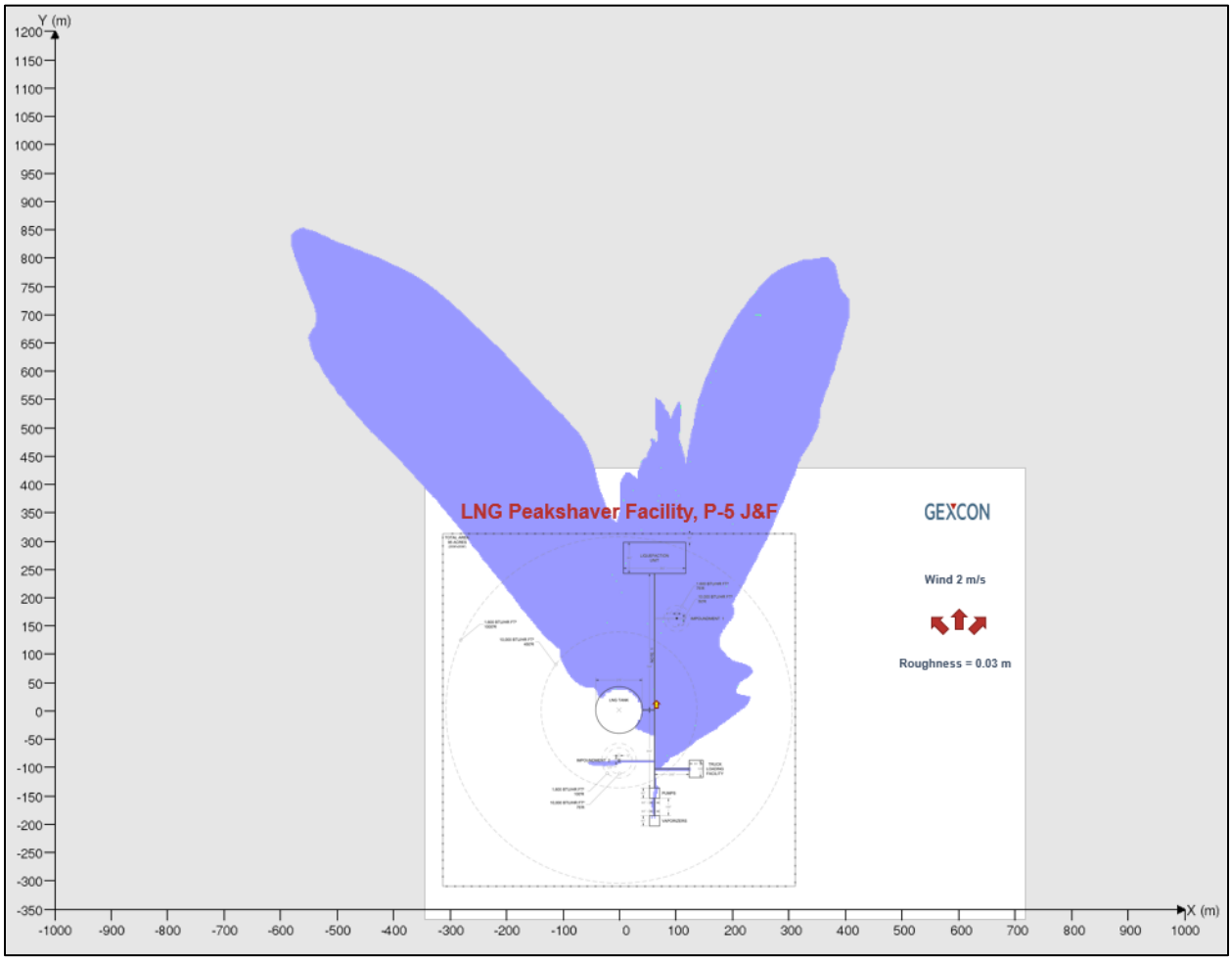

Figure 30.2-2: LP Sendout Line Unmitigated (North)

A 20-foot-tall solid vapor fence has been placed along the all perimeter property lines. The results of the jetting and flashing vapor dispersion modeling with the inclusion of the vapor fence is illustrated in the following figures:

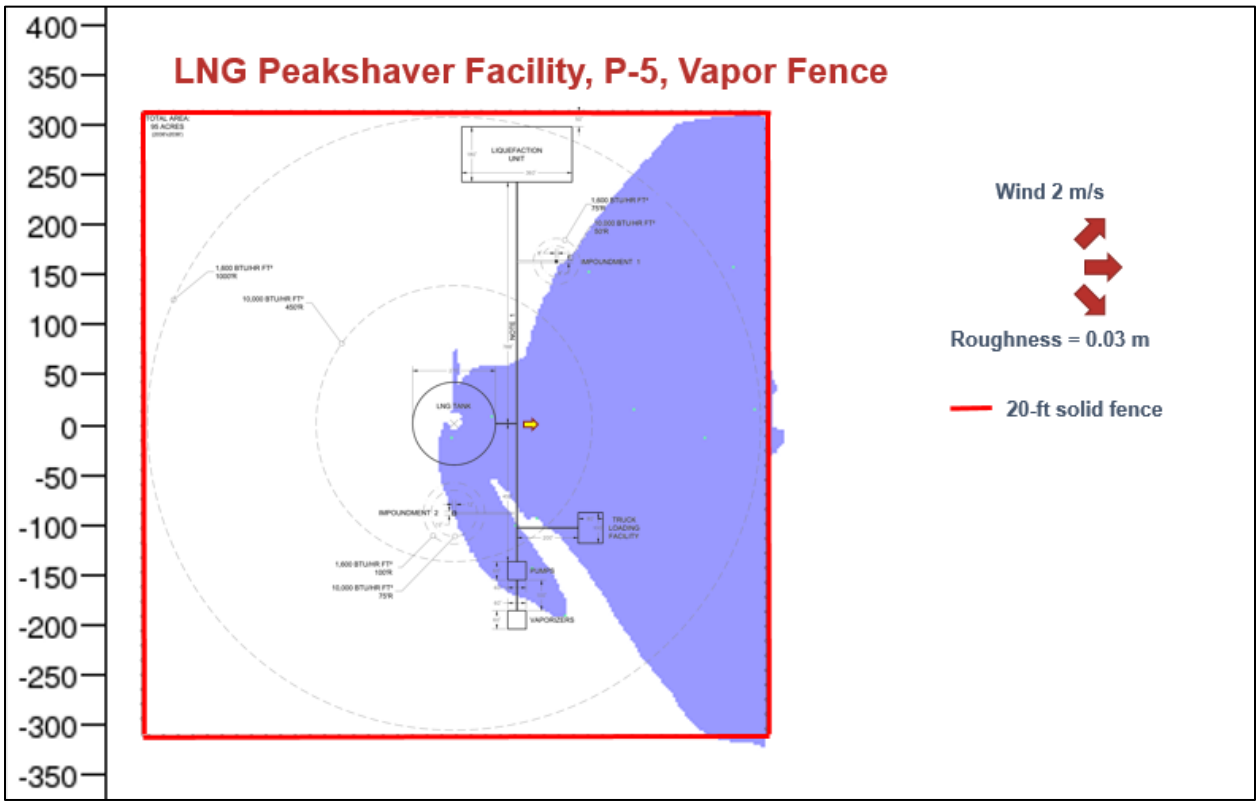

Figure 30.2-3: LP Sendout Line Mitigated (East)

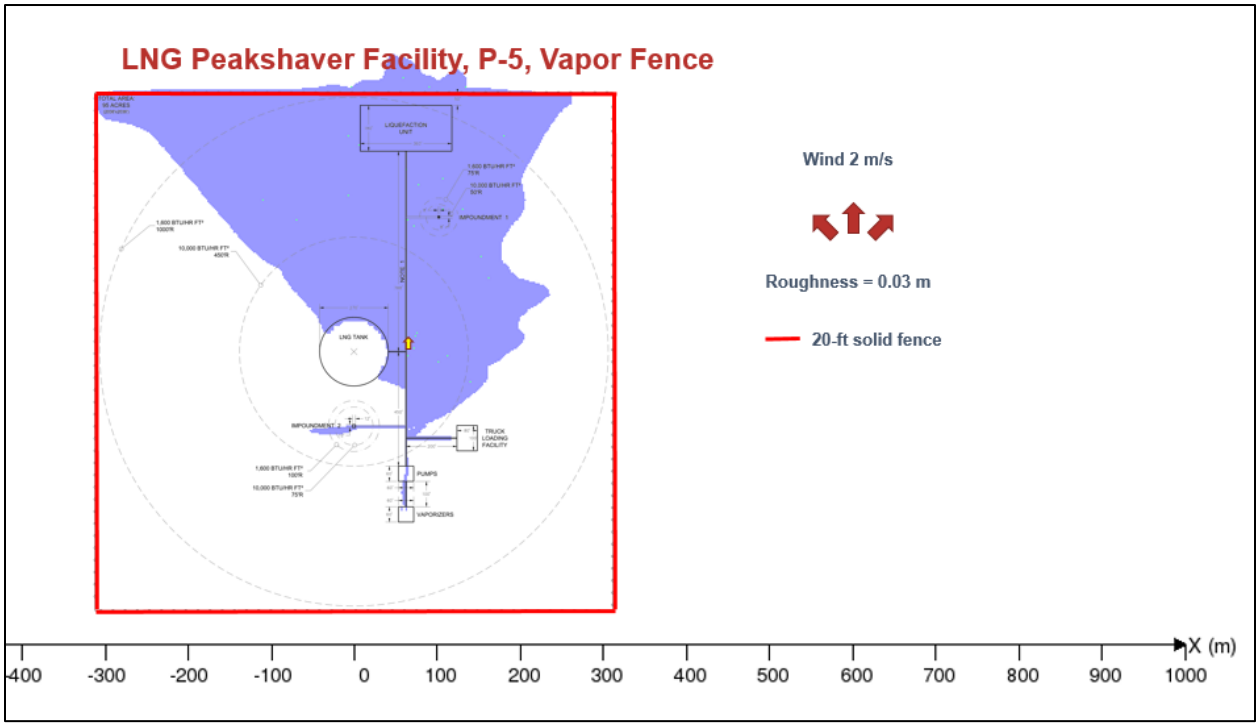

Figure 30.2-4: LP Sendout Line Mitigated (North)

As detailed in the figures above, the addition of passive vapor fences provides an obstruction to contain LNG vapors and can have a significant impact on the vapor dispersion exclusion zone.

The initial unmitigated release showed significant cloud travel across the East and North property lines. When the vapor fence was added, it provided vapor holdup and had an impact on the overall shape of the vapor dispersion exclusion zone. However, as the mass flow rate from the release remained unchanged, the amount of LNG spilled during the release remained unchanged.

The release to the East was unobstructed until it hit the vapor fence. However, due to the height of the fence, the large mass of the cloud accumulated at the base of the vapor fence and was channeled North and South along the fence remaining inside the property line. Only a very small portion of vapor extends across the top of the fence. The vapor fences resulted in an approximate 65% reduction in vapor dispersion exclusion zone distance.

The release to the North was mostly unobstructed until it hit the vapor fence with minor obstructions associated with the liquefaction train. However, due to the height of the fence, the large mass of the cloud accumulated at the base of the vapor fence and was channeled East and West along the fence remaining inside the property line. Only a very small portion of vapor extends across the top of the fence. The vapor fences resulted in an approximate 60% reduction in vapor dispersion exclusion zone distance.

<u>HP Sendout Line:</u>

The following figures shows the initial results of scenarios P-10 unmitigated:

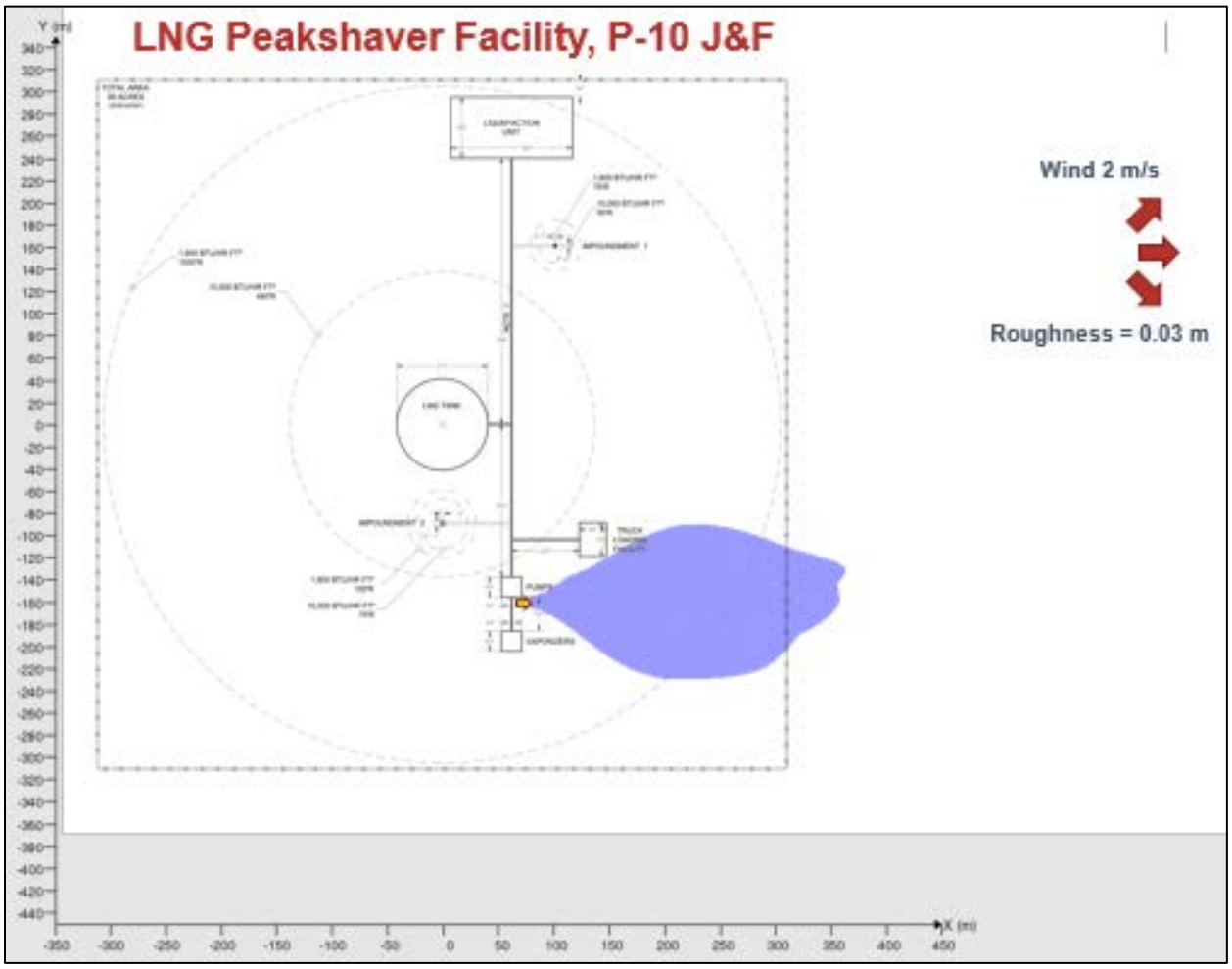

Figure 30.2-5: HP Sendout Line Unmitigated (East)

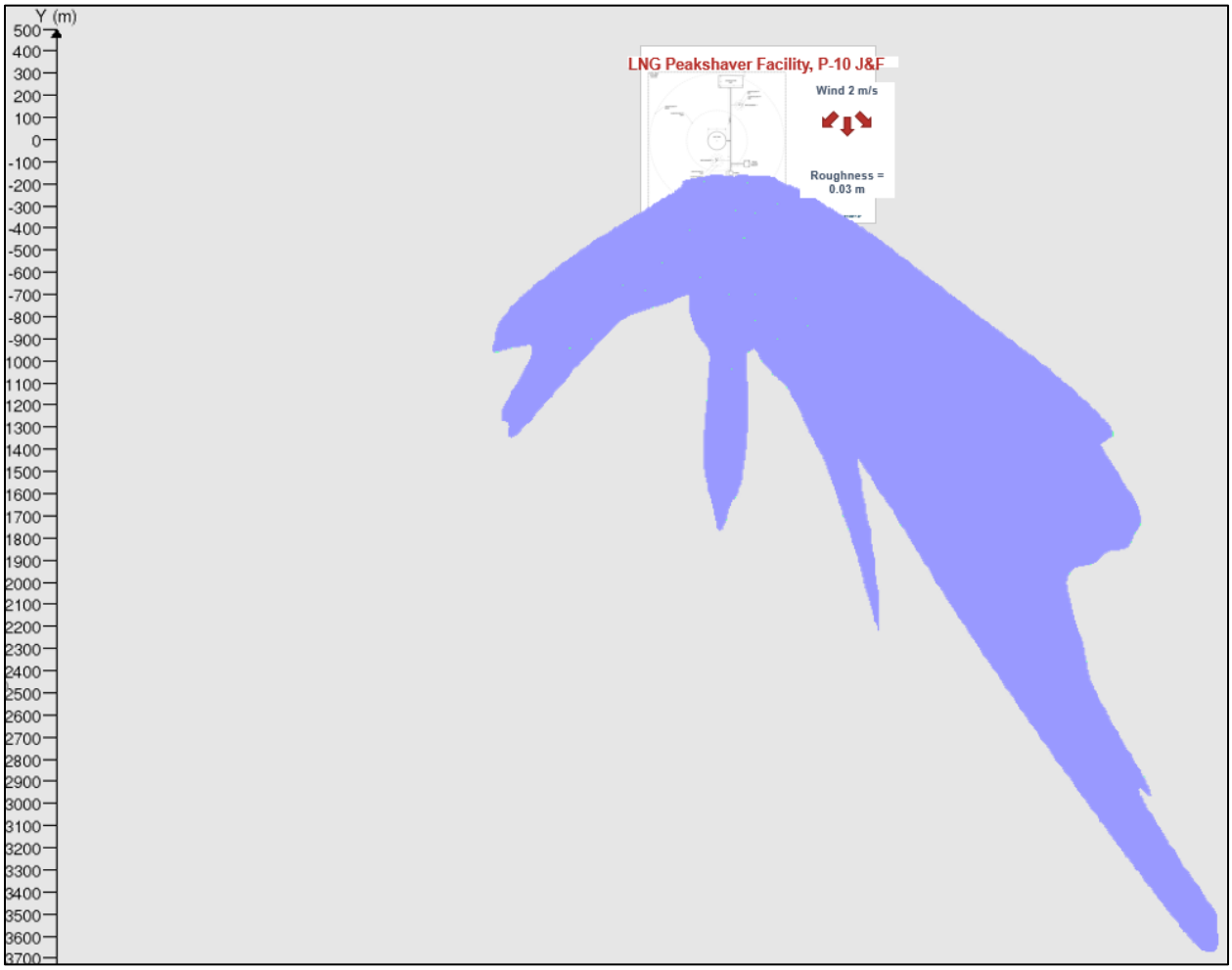

Figure 30.2-6: HP Sendout Line Unmitigated (South)

A 20-foot-tall solid vapor fence has been placed along the all perimeter property lines. The results of the jetting and flashing vapor dispersion modeling with the inclusion of the vapor fence is illustrated in the following figures:

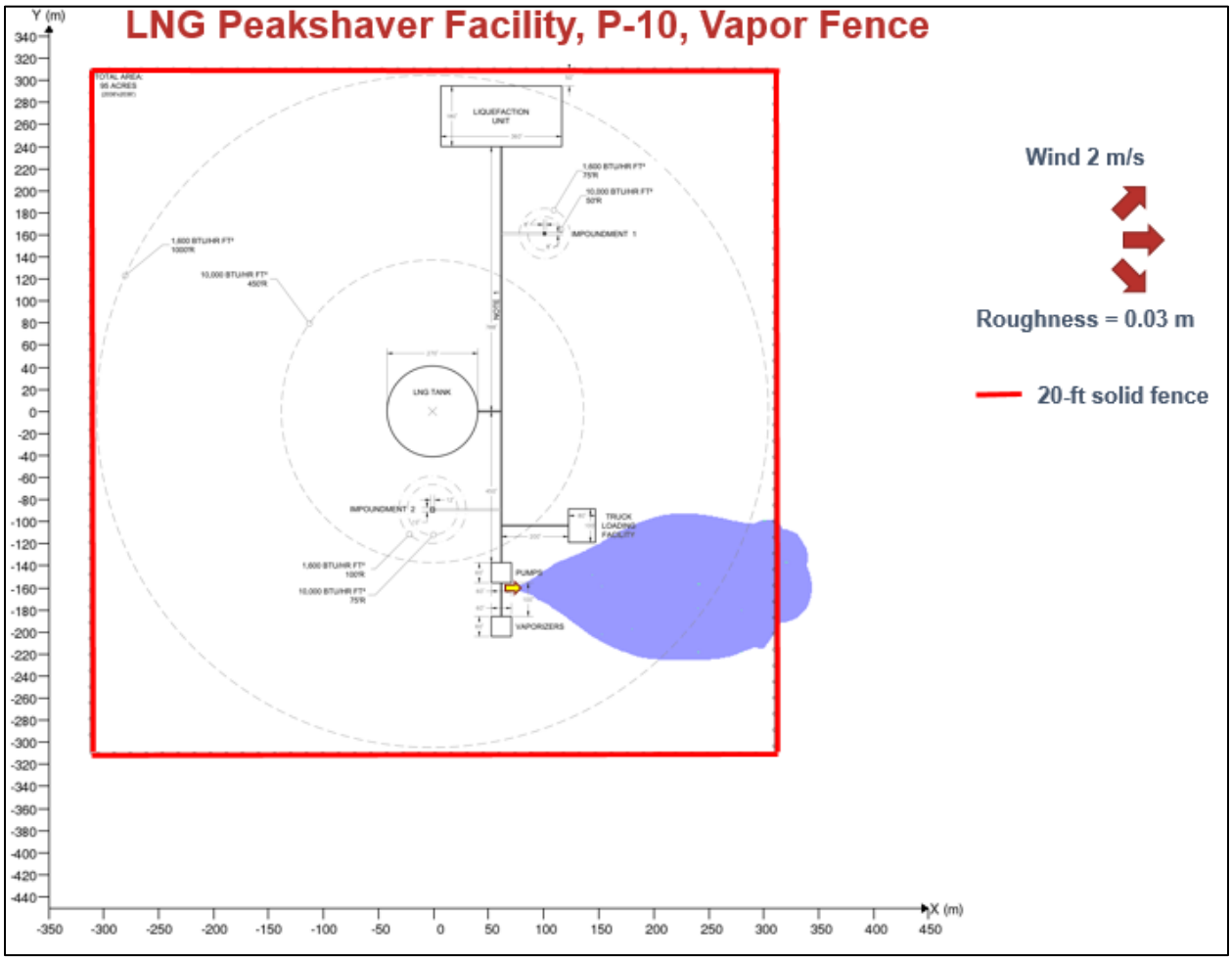

Figure 30.2-7: HP Sendout Line Mitigated (East)

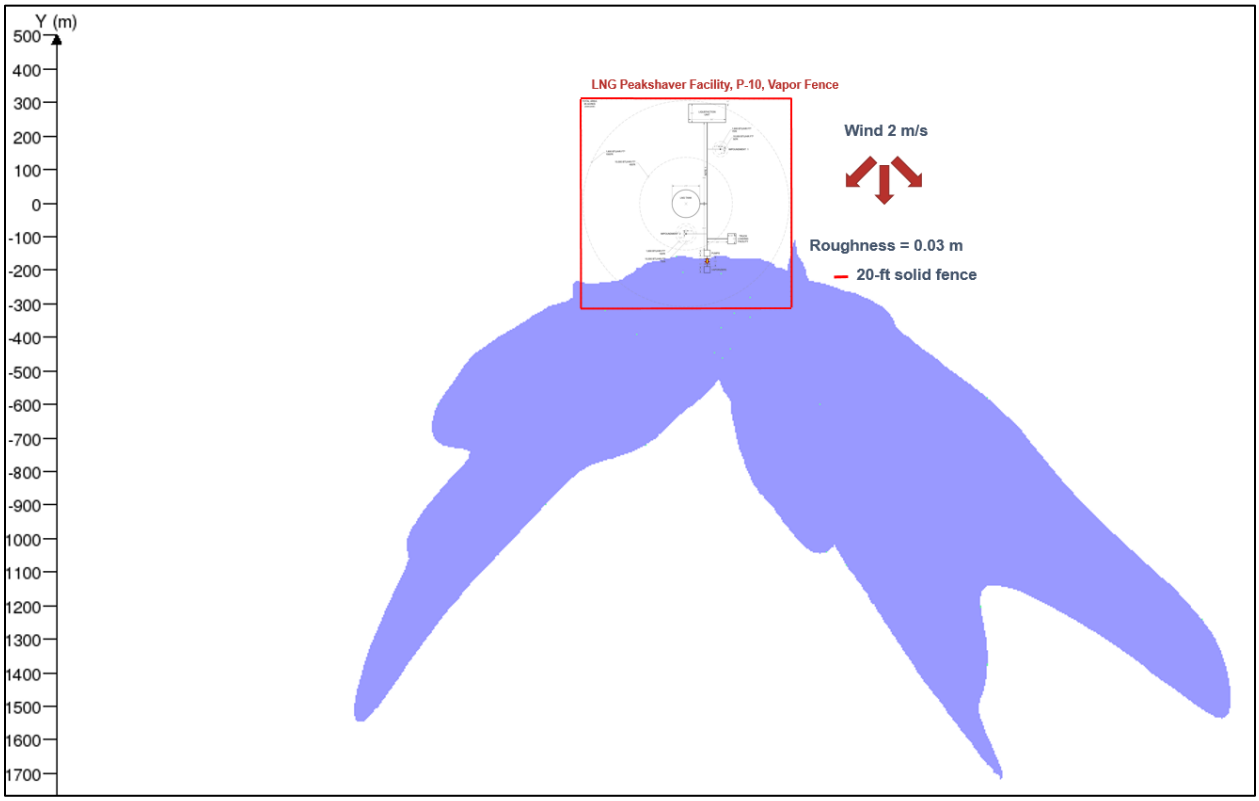

Figure 30.2-8: HP Sendout Line Mitigated (South)

As detailed in the figures above, the addition of passive vapor fences results in a solid barrier which provides an obstruction to contain LNG vapors and can have a significant impact on the vapor dispersion exclusion zone.

The initial unmitigated release showed significant cloud travel across the East, South, and West property lines. When the vapor fence was added, it provided vapor holdup and had an impact on the overall shape of the vapor dispersion exclusion zone. However, as the mass flow rate from the release remained unchanged, the amount of LNG spilled during the release remained unchanged.

The release to the East was unobstructed until it hit the vapor fence. However, due to the height of the fence and the high pressure of the release, a small portion of vapor extends across the top of the fence. The vapor fences resulted in an approximate 10% reduction in vapor dispersion exclusion zone distance.

The release to the South was mostly unobstructed until it hit the vapor fence with minor obstructions associated with the liquefaction train. However, due to the height of the fence and the high pressure of the release, a large portion of the cloud still travels over the fence. The vapor fences resulted in an approximate 50% reduction in vapor dispersion exclusion zone distance.

31 MITIGATED VAPOR DISPERSION MODELING RESULTS CONCLUSION

All mitigation modeling scenarios demonstrate a significant reduction in vapor dispersion distances compared to the unmitigated modeling scenarios. As the hole sizes are unchanged from the unmitigated modeling scenarios, the resulting vapor dispersion distances with mitigation measures are still driven by the hole sizes of the release.

The use of PERC valves or breakaway couplings in marine transfer systems can result in a negligible volume of LNG being released in an emergency, thereby significantly reducing vapor dispersion exclusion zones which are currently based on full guillotine ruptures of transfer hoses.

With properly designed shutdown systems and proper placement of gas detection devices, the use of Emergency Shutdown systems resulted in a decrease of up to 64% in vapor dispersion exclusion zones.

With proper placement of vapor fences, the use of vapor fences resulted in a decrease of up to 65% in vapor dispersion exclusion zones. Additional decreases can be seen by adding in additional layers of vapor fences or by increasing the heights of vapor fences.

Additional decreases can be seen by the use of a combination of mitigation measures, such as consideration for Emergency Shutdown systems along with the placement of vapor fences as the use of Emergency Shutdown systems will reduce the amount of mass released in an emergency.

There are numerous mitigation options available to mitigate vapor dispersion scenarios for LNG facilities which are not commonly taken into account when determining vapor dispersion exclusion zone distances. Accounting for those mitigation options in future exclusion zone determinations can have a significant decrease on the overall exclusion zone size and can also promulgate use of additional mitigation measures by LNG facility operators to minimize the potential for hazards to the public.

The mitigation modeling scenarios were performed to provide examples of the effectiveness of mitigation features and are not site specific. The use of mitigation features in modeling should be site specific, using vendor supplied information for ESD systems and actual site configurations and heights of vapor fences.

TASK 4C: VAPOR DISPERSION EXCLUSION ZONE GRAPH

32 BACKGROUND

During the initial phases of projects, many developers need to understand if a parcel of land is suitable for the proposed project. Based on the updated hole size criteria to determine vapor dispersion exclusion zones, several parameters necessary to calculate vapor dispersion exclusion zones are not available until the project is well into the design phase. Therefore, the below graph can be used by developers to get an understanding of what an unmitigated, jetting and flashing vapor dispersion exclusion zone may look like for their proposed project using the Phast model.

It should be recognized that this graph has been highly generalized and that a site-specific analysis is still required once the developer determines that a project is feasible and the design progresses. Projects must still comply with 49 CFR Part 193 and follow DOT PHMSA FAQ's posted on their website for actual exclusion zone determination. This graph is not a substitute for a full hazard analysis to demonstrate compliance with 49 CFR Part 193.

33 VAPOR DISPERSION EXCLUSION ZONE GRAPH

Based on the current set of DOT PHMSA FAQ's (2017 Requirements), the majority of hole sizes for all LNG piping will be 2 inch, 3 inch or 4 inch holes. Therefore, a graph has been created for these hole sizes, along with a 1 inch hole for other applications, with increasing pressures using the Phast model.

The graph uses a fixed atmospheric temperature of 80ºF, wind speed of 2 m/s, a surface roughness factor of 0.03m, relative humidity of 50%, and an atmospheric stability class of F.

There are many site-specific parameters used for calculating a final exclusion zone determination, such as ambient temperature, wind speed, relating humidity, surface roughness, atmospheric stability, process conditions (temperature, pressure, and available flow rate), release orientation, release height, etc. In addition, there are many other site-specific factors which may have an impact on vapor dispersion distance, such as geometry, terrain, mitigation measures, etc. All of these variables cannot be illustrated with a single graph and therefore conservative assumptions have been made to fix all variables except for hole size and pressure.

It should also be recognized that this graph is unmitigated and as shown in previous sections, the use of facility geometry, ESD valves, vapor fences, or other site-specific conditions or mitigation measures can have a significant impact on vapor dispersion exclusion zones and can result in reductions to vapor dispersion exclusion zones. Therefore, if these graphs illustrate that a highly conservative non-facility specific unmitigated exclusion zone would travel offsite, there are numerous aspects which could reduce those exclusion zones as detailed in previous sections of this Report.

The graph also does not take into account any depressurization or inventory loss effects which could be observed in process piping and assume that there is sufficient flow in all piping to sustain the release. Therefore, the graph assumes that the pressure in the piping is maintained and no depressurization occurs.

Since many process parameters and design conditions are fixed in the graph, once a project's engineering design is developed, actual process conditions and design parameters should be used to develop a full siting analysis which will serve as the basis for determination of compliance with 49 CFR Part 193.

Process conditions typical to the LNG facilities evaluated in this report are described in Sections 10, 11, 12, and 13 for each facility type.

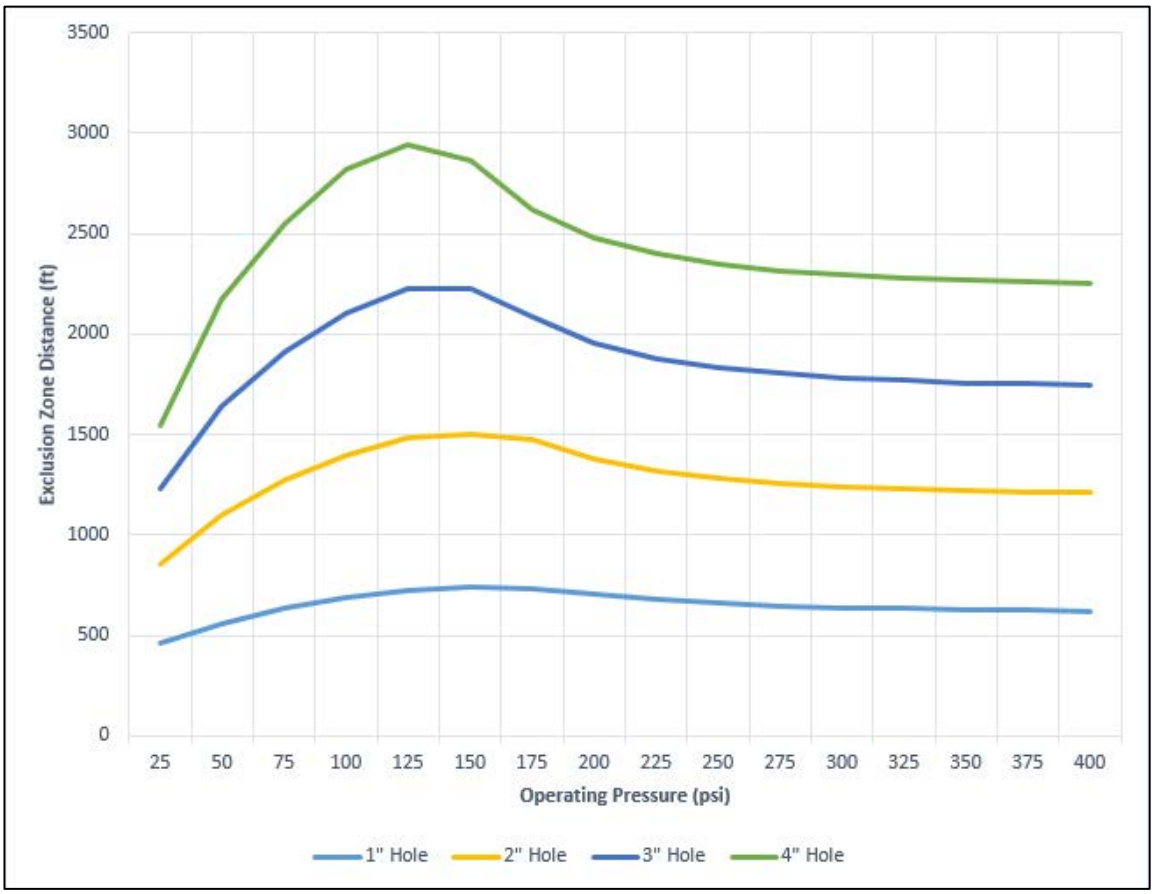

Figure 33: Sample Vapor Dispersion Exclusion Zone Graph

The graph above depicts a "peak" for each size hole at a different pressure. This trend is the result of the various parameters of the Phast model used to determine the final vapor dispersion distance. Phast's advanced droplet model indicates that for lower pressure releases, the droplet formation in the aerosol model creates a vapor cloud that takes longer to disperse when compared to scenarios with higher release rates. The "peak" in the model indicates that there is droplet formation for lower velocity releases which impacts the energy and diffusion of the cloud as it moves down wind. This droplet formation may not be considered or may be handled differently by other models.

CONCLUSIONS AND RECOMMENDATIONS

All modeling performed for this Project was on a generic basis and is not site or process specific. As the determination of hole size is largely based on the actual facility design and layout, a site-specific analysis is always required to determine the appropriate vapor dispersion exclusion zone for a given plant site. In addition, site specific parameters such as temperature, wind speed, humidity, elevation, terrain, overall layout configuration, and process conditions will have a direct impact on vapor dispersion exclusion zones. Therefore, the calculated exclusion zones in this report should not be interpreted as exclusion zones for all LNG facilities.

The results of the vapor dispersion exclusion zones show that the Phast, FLACS, and DEGADIS models generally provided similar results with most results within a factor of 2 across each model. However, comparison across all models did vary from release to release based on the physical properties, plant geometries, locations, and sizes of each release. The FLACS model was run with and without including facility geometries and the results indicate that the inclusion of geometry has a direct impact on the results. All mitigation features used in the mitigation modeling was used to illustrate the potential benefits of mitigation features on vapor dispersion exclusion zones. The use of mitigation features and the quantification of mitigation features should be site specific.

This Project was initiated in September 2015 and therefore used the DOT PHMSA FAQ requirements at the time (revised 12/7/2015) to calculate vapor dispersion exclusion zones (2016 Requirements). Many of the larger exclusion zones are driven by the 2016 Requirements to determine a single accidental leakage source hole size based on length, which includes large diameter, solid welded piping. Towards the end of this research project and after completion of the GTI Failure Rate Table Research Project, on January 10, 2017, DOT PHMSA updated its FAQ to simplify the methodology for determining a single accidental leakage source which resulted in hole sizes on the order of 2 inch, 3 inch and 4 inch. Therefore, the failure rate based requirements which were driving the very large hole sizes detailed in this report were removed after completion of Tasks 4A and 4B which illustrated the results of very large hole sizes. This January 10, 2017 update no longer requires the use of the failure rate table and provides more single accidental leakage source hole sizes based on credible releases informed by the GTI report (2017 Requirements). It is recommended that applicants review the requirements of 49 CFR Part 193 and the FAQ's posted on the DOT PHMSA website to ensure the current methodology for determining a single accidental leakage source is followed after issuance of this Final Report and completion of this Project.

APPENDIX A – DOT PHMSA FAQ'S (REVISED 12/7/2015) – 2016 REQUIREMENTS

APPENDIX B – DOT PHMSA FAQ'S (REVISED 1/10/2017) – 2017 REQUIREMENTS